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INVESTIGATION OF LOW-LEVEL AIRCRAFT OPERATIONAL HAZARDS

November 1966

U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

CONTRACT DA 44-177-AMC-309(T)

NORTHROP CORPORATION
NORAIR DIVISION
HAWTHORNE, CALIFORNIA

U S ARMY MATERIEL COMMAND

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INVESTIGATION OF LOW-LEVEL AIRCRAFT OPERATIONAL HAZARDS

Prepared by

Northrop Corporation
Norair Division
Hawthorne, California

For

U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

ABSTRACT

This study evaluates the obstacle impact hazards incurred by operation of Army aircraft at treetop altitudes and describes techniques useful in alleviating those hazards. The magnitude of the problem of obstacle impacts is determined by a statistical analysis of aircraft tree strikes and wire strikes to identify the significant parameters involved. Investigation of sensor techniques and aircraft operating procedures is presented to aid development of obstacle warning systems.

FOREWORD

This report was prepared by the Systems Analysis Group of Northrop Norair, a Division of Northrop Corporation. The report represents the total effort performed under U. S. Army Contract DA 44-177-AMC-309(T), during the period July 1965 ending April 1966.

The work was administered under the direction of the U. S. Army Aviation Materiel Laboratories. Mr. J. L. Terry was the Project Engineer.

The program at Northrop Norair was performed under the direction of Mr. T. A. Bordeaux, Chief, Systems Analysis Group. Mr. J. F. Paris served as Project Supervisor for Northrop Norair.

The principal investigator was Mr. H. A. Ralles, and Northrop personnel who made major contributions to this research effort were: Messrs. J. R. Anderson, J. P. Campbell, M. B. Grier, D. R. Hansen, P. T. Koetz, R. P. Kramer, and D. L. Richartz.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont.)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont.)

LIST OF TABLES

LIST OF TABLES (Cont.)

I. INTRODUCTION

This report presents the results of a study performed by Northrop Corporation, Norair Division, of Hawthorne, California, for the U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, in compliance with U.S. Army Contract DA 44-177-AMC-309(T).

Norair has undertaken this study for the Army to identify and evolve techniques useful for mitigating hazards of low-altitude flight and to determine obstacle avoidance requirements associated with Army aviation and the air assault concept.

The study had three main objectives:

1. To assess the degree and type of obstacle impact hazard experienced by present and future Army aircraft during flight operations at and below treetop level.

2. To describe the equipment and/or operational procedures that may be utilized for obstacle avoidance.

3. To identify and assess aircraft design implications presented by potential equipment and procedures.

The scope of the study includes: (1) a statistical analysis of aircraft collisions with trees and wires to identify the significant parameters involved, (2) a determination of requirements for an airborne obstacle detection system, and (3) a description of system concepts which might reasonably be expected to meet those requirements.

The study included a review of the role of Army aviation and, more specifically, the Army air assault concept. The purpose of this review was to describe the operational environment in which aircraft were employed, the flight requirements that were imposed, and the types of missions that were flown.

An analysis of the impact hazards derived from Army aircraft accident statistics was made in depth to determine the type, magnitude, and frequency of obstacle impact hazards. A visit made to the Army Aviation Center at Fort Rucker, Alabama, for discussions with Army aviation personnel completed the review of present-day Army aviation operations.

Accident statistical data included service-wide operations, the several numbered Army areas, and the European and Alaskan theaters. Combat operations in Southeast Asia were not covered.

Several obstacle detection and warning system concepts were developed, including consideration of human factors and Army aircraft characteristics.

The data describing Army aircraft operations were obtained from field manuals, training manuals, and other specialized reports, including "Army Aircraft Availability Statistical Digest" and "Air Assault in Action." The accident statistics were received from U.S. Army Board for Aviation Accident Research. Information concerning millimeter radar was obtained from Norden Division of United Aircraft Corporation and from Emerson Electric Corporation. A complete list of the documents reviewed is contained in the bibliography.

II. SUMMARY

OBJECTIVES AND SCOPE

A major objective of this study was to analyze Army aircraft accident statistics to determine the magnitude, frequency, and major causal factors of Army aviation accidents involving tree and wire strikes during in-flight operations based on past and projected operations. A secondary objective of the study was the exploration and evaluation of sensor technology to determine if feasible and acceptable sensors are available for use in developing operational obstacle-avoidance equipment.

The scope of the accident investigation includes an analysis of data for accidents involving tree and wire strikes from FY 1958 to the middle of FY 1965. Flying-hour data for the period beginning with FY 1963 through the first half of FY 1965 are correlated to accidents for a determination of rates per 100,000 flying hours for the period. Statistical data do not include any operations in combat.

As a corollary to the primary investigation, certain operational procedures are investigated by time line analysis, observation, and study of training syllabi to determine areas of possible improvements in technique or flying training that would reduce obstacle impact accidents.

Application of both active and passive sensor technology is investigated to determine the most feasible concept to solve the problem of obstacle avoidance. Non-equipment solutions are also considered, i.e., the addition of observers and observer stations. Several concepts for landing aids are also suggested as a result of the study.

CONCLUSIONS

It is concluded that:

1. Rotary-wing aircraft have the highest incidence of tree and wire strike accidents.

2. Within the rotary-wing class of aircraft, the utility and observation types of aircraft have the highest obstacle strike rates per flying hour.

3. For fixed-wing aircraft, higher speeds correlate directly with rate of obstacle strikes.

4. The three cause factors in the order of their importance are as follows:

   a. Pilot inexperience.

b. Errors in judgment, time, and distance in relation to aircraft capability.

c. Inability to see the obstacle (wire) in sufficient time.

5. Optical radar (laser) presents the most feasible and practical sensor capability for a potential obstacle-avoidance system. The development of such a system appears to be within the capability of current technology; however, size, weight, and cost factors were not considered.

6. Assignment of an observer or assignment of additional duties to a crew member to provide additional visual scan for wire hazards can provide an easily implemented and inexpensive solution on an interim basis.

7. Since a high incidence of impact accidents occurs in the landing phase, glide slope landing aids could be of assistance. Although primarily limited to use on prepared airstrips, certain equipment is capable of field application and can be used by either fixed- or rotary-wing aircraft.

RECOMMENDATIONS

It is recommended that:

1. Since current and future Army aviation operations will involve increased low-level missions, additional dual low-level flight training be included in the current training program.

2. Obstacle hazard briefings be included as a standard item of preflight briefings. Use of safety posters and other visual training aids would also emphasize the need for alertness.

3. Additional early monitoring of student progress be impletmented to insure that he is not inadvertently exposed to situations that would overtax his ability.

4. Doctrine for laying of field communications wire include a requirement for notices to airmen (NOTAM) when hazards are created.

5. Consideration be given to the inclusion of an observer on flights known to be exposed to wire hazards.

6. Operational evaluations be conducted on available approach and glide slope equipment to determine its applicability.

7. Active development of an obstacle-avoidance system based on the use of optical radar be pursued. Steps in this development would include further definition of:

a. Detailed requirements in respect to capability, size, weight, and power.

b. Autopilot applications of sensor inputs.

c. Sensor field of view requirements.

d. Integration or interface problems with terrain-following equipment and other features of the Integrated Helicopter Airborne Avionics System (IHAAS).

8. Current medical standards for Army pilots be further studied and evaluated. Possible changes in visual criteria may be indicated, with particular emphasis on depth perception.

9. Current emphasis on safety training, particularly in the earlier phases of flight training, be continued.

III. REVIEW OF HISTORICAL DATA

As background to the presentation of the data on collisions with obstacles during low-level flight operations, the operational environment is described. The current inventory of aircraft is shown with the physical and performance characteristics of each model necessary for the analysis of obstacle-avoidance concepts. An analysis of tree strike and wire strike accidents shows the major cause factors of such impacts, and a study of operational procedures identifies some areas which might contribute to low-altitude strikes.

The major mission categories and the distribution of flight hours in each category are presented as a basis for estimating future flight activity.

ARMY AIR MISSIONS AND FLIGHT HOURS

The primary combat air missions of Army aviation consist of:

1. Troop transport
2. Cargo transport
3. Ground fire suppression
4. Casualty evacuation
5. Reconnaissance
6. Message drop and pickup
7. Liaison and courier
8. Wire laying
9. Search and rescue

Other missions may include battlefield illumination, smoke laying, emergency resupply, observation, artillery spotting, and photography. This study is primarily concerned with activities carried on by operational aviation units. These missions are performed by either fixed-wing or rotary-wing aircraft. They primarily take place over division airspace and during an airborne assault operation may be projected forward of the FEBA. In these cases, armed escort aircraft may be provided for the purpose of ground fire suppression. Many of the missions must be flown at as low an altitude as possible to maintain cover from visual and radar observation and to achieve surprise. The resultant increased flight hazard from trees, towers, wires, and other ground obstructions is readily apparent. Although the pilot is perforce more alert to these dangers while

flying at treetop level, his workload is magnified because of distractions resulting from navigation duties, turbulent air, formation flying, reduced visibility, and the increased tension associated with low-level flight.

Army aviation is basically oriented in its operations to the ground missions, and as a result it operates in the environment of the land battle. A total aircraft inventory in excess of 7,000 aircraft of all types dispersed throughout the Army organization has the primary purpose of increasing the ground forces' mobility.

The present Army ROAD division has 101 aircraft made up of 97 helicopters and 4 fixed-wing aircraft. The airmobile division has 434 aircraft: 428 helicopters and 6 fixed-wing aircraft. By contrast, the WW II division had less than 12 aircraft and the Korean division only 26. After extensive field evaluations, the 11th Air Assault Division, redesignated the 1st Cavalry Division (Airmobile), is now operating in South Vietnam. Its organization structure is shown in Figure 1. With the ever-increasing tempo of Army aviation activities, the problem of collision with ground obstacles has become a serious matter. For example, although helicopter losses to enemy action in Vietnam have been phenomenally low (one for every 13,000 flights), the losses to other causes have been relatively high. It was reported that 177 helicopters were lost during 1965, with 76 lost to enemy fire. It is not known how many of the 101 lost to other than enemy actions were the result of collision with low-level obstacles, but on the basis of data presented, it can be assumed that it was significant. With the increasing pattern of success in the use of the Army's airmobile concept, additional means must be found to aid the pilot in early detection of obstacle hazards.

Flight-hour statistics for various types of Army aircraft are shown in Tables 1 and 2, giving total Army-wide operations as well as details concerning the 11th Air Assault Division. It is noticed in Table 1 that some seasonal shift can be detected for the O-1, U-1, U-6, OH-13, and the CH-34 types. The CV-2, UH-1, and CH-47 all show a strongly increasing trend in flight hours, the result of significant increases in numbers of operating aircraft during the period.

More than half of the 11th Air Assault Division's flying hours were performed by UH-1 aircraft. The next highest in terms of flight hours was the CV-2 Caribou, averaging about one-half the hours of UH-1 aircraft.

ARMY AIRCRAFT: CURRENT INVENTORY

Table 3 presents the inventory of aircraft used in compiling the flight hours on the preceding tables and their average aircraft utilisation rates. It will be noted that fixed-wing aircraft generally have a higher utilization rate than rotary-wing aircraft.

Aircraft turning performance capability determines the amount of space required to avoid obstacle hazards. Table 4 lists the basic charac-

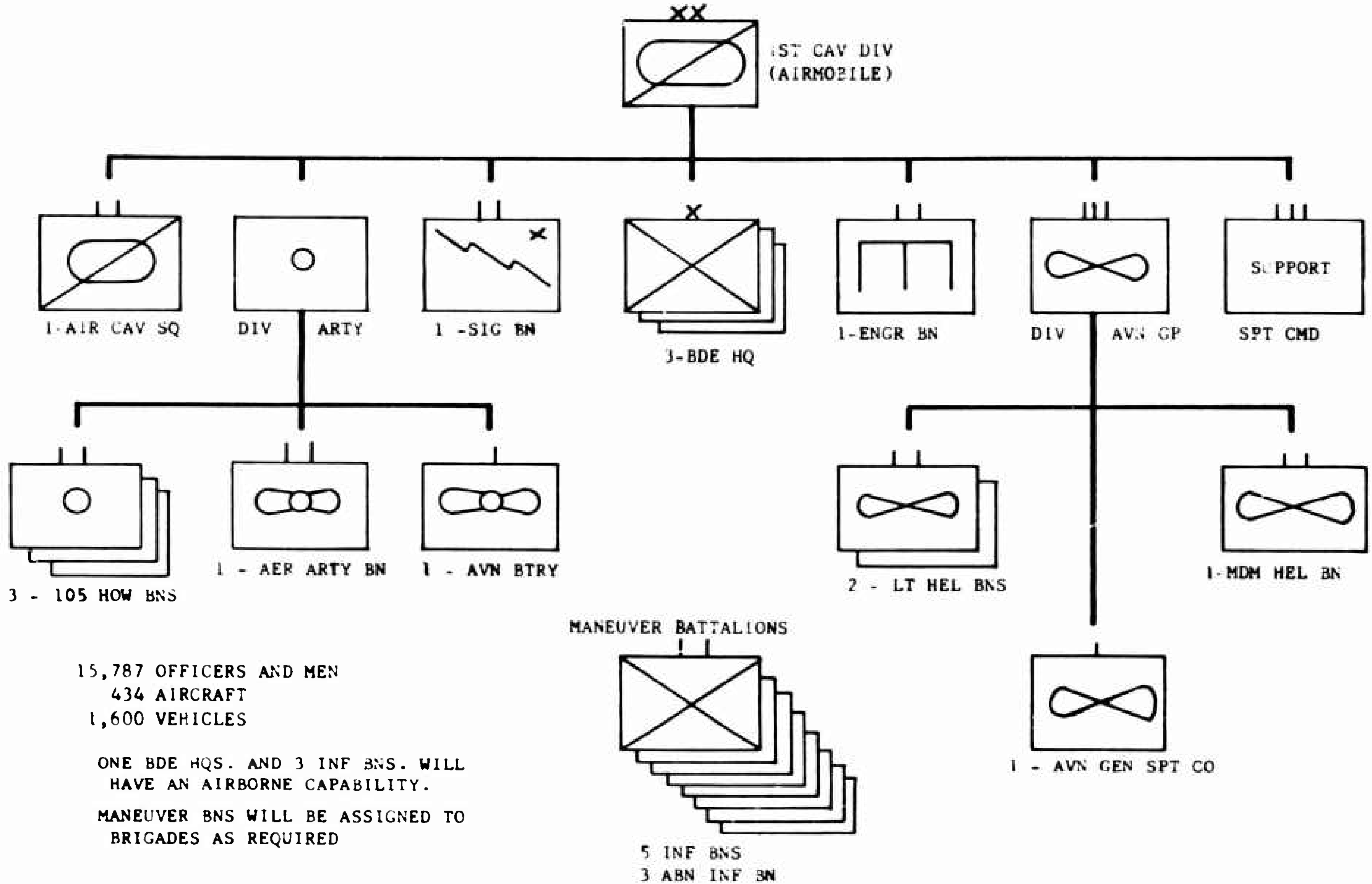


FIGURE 1. AIRMOBILE DIVISION ORGANIZATION CHART

TABLE 1

FLIGHT HOURS RECORD

	FY 1963				FY 1964				FY 1965	
	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter	1st Quarter	2nd Quarter
0-1 BIRD DOG	145,932	100,150	102,717	138,171	163,111	122,559	119,411	154,102	146,691	106,927
U-1 OTTER	18,285	14,965	13,704	16,183	18,957	15,009	13,873	16,313	16,314	12,788
U-8 SEMINOLE	26,061	26,321	25,138	29,342	28,819	25,613	25,613	28,263	28,860	27,225
CV-2 CARIBOU	4,849	6,270	7,443	8,139	12,050	12,661	14,152	19,462	19,628	25,457
OV-1 MOHAWK	4,458	4,960	6,070	7,805	8,558	7,835	8,263	9,909	9,835	9,675
U-6A BEAVER	75,852	59,660	55,704	70,137	73,841	60,517	59,673	76,724	72,568	59,653
OH-13 SIOUX	49,737	38,575	33,956	42,335	39,347	29,298	28,052	42,562	36,651	32,353
OH-23 RAVEN	53,603	45,123	54,280	62,620	74,020	59,430	57,458	73,629	76,151	71,091
UH-1 IROQUOIS	20,072	18,812	20,513	34,871	47,921	59,234	65,195	87,152	94,594	109,001
UH-19 CHICKASAW	17,502	14,978	12,433	14,549	17,190	13,823	15,800	21,777	22,525	18,225
CH-21 SHAWNEE	17,900	19,417	17,396	17,602	15,131	13,280	12,847	10,313	7,571	6,468
CH-34 CHOCTAW	28,780	19,553	19,948	24,822	24,294	17,099	15,640	19,289	17,141	12,216
CH-37 MOJAVE	3,805	3,461	3,955	4,800	4,423	3,435	4,130	4,789	3,548	3,540
CH-47 CHINOOK	10	71	416	887	1,261	818	891	2,587	3,055	4,459

TABLE 2

11TH AIR ASSAULT DIVISION FLIGHT HOURS

	FY 1964		FY 1965	
	3rd Quarter	4th Quarter	1st Quarter	2nd Quarter
U-8 SEMINOLE	182	138	170	177
CV-2 CARIBOU	6862	10,435	10,527	16,549
OV-1 MOHAWK	2194	2455	2806	3494
U-6A BEAVER	929	926	711	767
OH-13 SIOUX	3103	6192	8291	7958
UH-1 IROQUOIS	11,021	21,053	27,827	27,762
CH-37 MOJAVE	1256	1369	892	1146
CH-47 CHINOOK	641	1811	2638	4245

TABLE 3

U.S. ARMY AIRCRAFT INVENTORY
JANUARY 1965

	AVERAGE UTILIZATION HRS/MO	NO. AIRCRAFT
FIXED-WING		
O-1 BIRD DOG	30 - 35	1539
OV-1 MOHAWK	18 - 20	175
U-1 OTTER	30 - 35	160
U-6 BEAVER	35 - 40	614
U-8 SEMINOLE	35 - 40	254
CV-2 CARIBOU	60 - 65	135
ROTARY-WING		
OH-13 SIOUX	15	878
OH-23 RAVEN	25	962
UH-1 IROQUOIS	35	1009
UH-19 CHICKASAW	30	247
CH-21 SHAWNEE	15	241
CH-34 CHOCTAW	20	340
CH-37 MOJAVE	15	86
CH-47 CHINOOK	25	63

TABLE 4

ARMY AIRCRAFT CHARACTERISTICS

	GROSS WT. (lb)	MAX SPEED (Knots)	MAX LOAD FACTOR	STALL SPEED (Knots)	SPAN (Ft)	LENGTH (Ft)	HEIGHT (Ft)	TURN RADIUS MAX SPEED MAX LOAD FACTOR (Ft)
FIXED-WING								
O-1 BIRD DOG (L-19)	2,400	98	4.4	43	36.0	25.8	7.5	209
U-1 OTTER	8,000	125	3.5	50	58.0	41.8	13.0	412
U-6 BEAVER	5,100	125	3.5	52	48.0	30.4	10.4	412
U-8 SEMINOLE (L-23)	7,700	203	4.4	69-70	45.9	33.3	14.2	850
CV-2 CARIBOU	28,500	165	2.6	60	95.7	72.6	31.8	900
OV-1 MOHAWK (AO-1)	12,000	275	5.0	80-90	42.0	41.0	12.7	1,370
ROTARY WING								
OH-6 LOH	2,100	125			26.3	30.0	8.1	700
OH-13 SIOUX	2,350	87	2.5		35.1	41.4	9.8	293
OH-23 RAVEN	2,800	83	4.0		35.4	40.7	9.3	200
UH-1 IROQUOIS	8,500	118	2.25		48.0	57.1	13.7	452
UH-19 CHICKASAW	8,100	96	2.4		53.0	62.3	13.3	375
CH-21 SHAWNEE	13,500	120	2.75		44.0	86.3	15.4	620
CH-34 CHOCTAW	13,000	105	2.33		56.0	65.8	14.3	466
CH-37 MAJAVE	31,000	118	2.45		72.0	88.0	16.0(Approx.)	500
CH-47 CHINOOK	33,000	150	1.5		59.1	98.2	18.5	1,785
XC-142 TRI-SERVICE V/STOL	37,000	375	3.0		67.5	58.1	26.1	3,800

teristics of currently operational U.S. Army aircraft, both fixed wing and rotary wing. Detailed lift/drag relationships and other performance capabilities are proprietary and were not available to the Contractor. In lieu of complete performance data, the turning capabilities of these aircraft models were computed on the basis of published values of maximum velocity and the following relationships:

$$R = \frac{V^2}{g(n^2 - 1)^{\frac{1}{2}}}$$

where

R = Turning radius, feet

V = Velocity, ft/sec

g = Gravity acceleration, 32.2 ft/sec^2

n = Normal load factor

The accuracy of the performance estimates makes any distinction between horizontal maneuver and vertical maneuver merely an academic exercise. For simplicity, then, the turn radius and pull-up radius are assumed to be the same.

The computed values of turn radius shown on Table 4 are considered to be conservative in the determination of requirements for an obstacle-detection system. At maximum speed, the significant increase in angle of attack accompanying a turn will also result in reduced speed and shorter turn radius, i.e., a decelerated turn. Figure 2 shows the relationship of turn radius to velocity for each of the aircraft listed on Table 4. It is seen that the load factors allowed for fixed-wing aircraft are consistently higher than for rotary-wing aircraft, allowing the fixed-wing aircraft to turn in a shorter radius. Figure 2 illustrates the narrow bands which encompass the velocity-turn radius relationships for the two classes of Army aircraft.

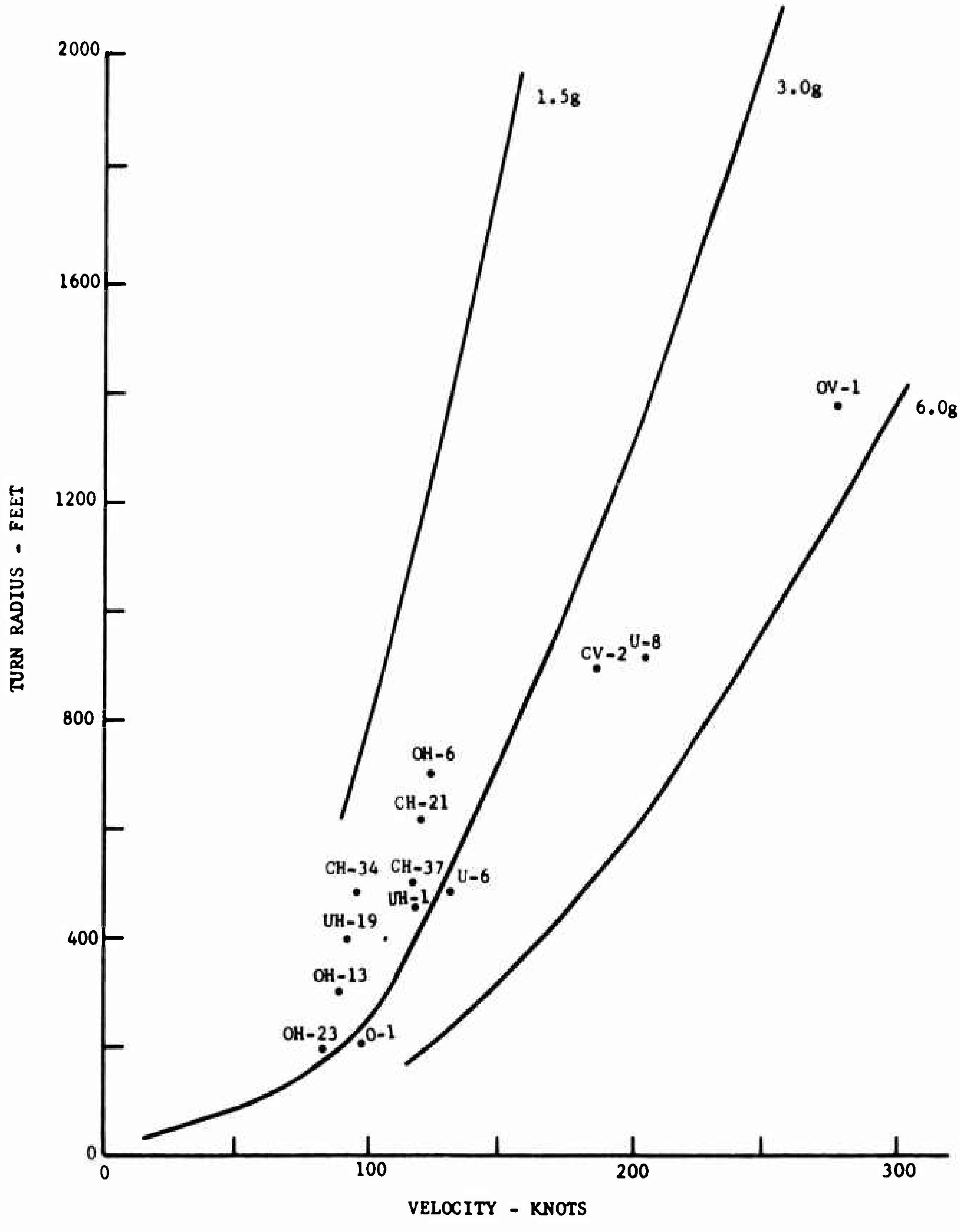


FIGURE 2. AIRCRAFT MANEUVER TURN RADIUS

ANALYSIS OF LOW-ALTITUDE ACCIDENT STATISTICS

The accident analysis was used as an aid in identifying the problems of low-altitude flight. From this analysis, the causes of obstacle strikes and the conditions associated with obstacle strikes were also determined within the limits of the data available. The relationship of the obstacle strikes to the total Army aircraft operation was not determinable because the flight-hour distribution by hour of the day, type, model of aircraft, pilot characteristics, etc., was not available.

Accident Statistics

The accident statistics investigated are divided into four major groups:

1. Rotary-wing tree strikes
2. Rotary-wing wire strikes
3. Fixed-wing tree strikes
4. Fixed-wing wire strikes

These statistics include all the U.S. Army aviation tree and wire impacts in the period from the 1st Quarter FY 1958 to April 1965, excluding combat area occurrences. The operational factors recorded in the groups noted above are:

1. Aircraft type and model
2. Accident class (degree of aircraft damage)
3. Hour of the day
4. Accident type (tree strikes and wire strikes)
5. Phase of operations: landing, takeoff, level flight, go-around, hover.
6. Pilot cause factors: misuse of aircraft controls, errors in spatial judgment, failure to see obstacles
7. Other personnel cause factors: service, maintenance, supervisory, aircraft crew, tower operators, etc.
8. Major command: basic army areas in the continental United States, Europe, Far East, Alaska, and the various training centers
9. Weather conditions: rain, fog, dust, snow, wind, icing, thunderstorms, gusts

10. Pilot experience levels in terms of years, flight hours, night flights, instrument hours, fixed-wing, rotary-wing

11. Flight mission: training, administrative, test, combat

12. Personnel injury: none, minor, major, critical, fatal

13. Pilot qualifications: fixed wing, rotary wing, rated in both, nonrated.

14. Pilot's previous accidents

15. Psychological cause factors

16. Physiological cause factors

Accident Data Evaluation

The foregoing factors are quantitatively summarized in Table 5, and complete detailed frequency distributions are presented in Appendix I. The most significant conclusion reached from the accident statistics is that the pilot causes predominate. The pilot cause factors are: (1) misjudged distance, altitude, or position, and (2) failed to see obstacle. The outstanding frequency of these two pilot cause factors in tree strikes and wire strikes suggests areas of increased training effort. A syllabus item in the training program might well include instruction in low-altitude evasive maneuvers to gain an appreciation of the time and distance factors required for obstacle avoidance.

Table 6 presents a summary of all the tree strikes and wire strikes reported for the 8-year period. These accidents are categorized by types of rotary-wing and fixed-wing aircraft involved. It is noted that tree strikes outnumber wire strikes approximately two-to-one for rotary-wing aircraft and three-to-one for fixed-wing aircraft. The primary hazard with wires is their lack of visibility.

Approximately 80 percent of all rotary-wing wire strikes resulted from a failure to detect the wires until it was too late. A comparison of wire strikes for fixed-wing aircraft indicates that 60 percent failed to see the wires. An examination of fixed- and rotary-wing tree strike cause factors reveals that approximately 46 percent, for both fixed and rotary aircraft, misjudged their distance, altitude, or spatial position.

Pilot experience also has a significant effect on obstacle strike rates. Figure 3 illustrates the cumulative obstacle strike rates for each of the four major categories as a function of pilot flight hours. It is of interest that 70 to 80 percent of the mishaps recorded involved pilots with less than 500 total flight hours. More importantly, approximately 50 percent of the mishaps involved pilots with less than 100 hours of total flight time. Approximately 33 percent of the total pilots at any one time

TABLE 5

STATISTICAL SUMMARY OF OBSTACLE IMPACT ACCIDENTS

		TYPE OF AIRCRAFT →	ROTARY-WING		FIXED-WING	
		TYPE OF OBSTACLE →	TREE	WIRE	TREE	WIRE
TOTAL NUMBER OF OBSTACLES IN SAMPLE			498	224	259	79
Accident Description (% of total accidents)*	Degree of Damage	Incidental	53	36	40	48
		Minor	10	15	20	22
		Substantial	27	28	18	17
		Total Destruction	10	21	22	13
	Extent of Personal Injury	None	90	75	84	87
		Minor	5	12	9	6
		Major to Fatal	5	13	7	7
	Type of Mission	Proficiency Trng.	10	14	16	25
		Student Training	26	13	49	23
		Tactical Training	9	11	8	16
		Transportation of Personnel	10	12	5	6
		All Others(Appen.A)	45	50	22	30
	Flight Phase	Takeoff	18	14	17	3
		Inflight	14	42	19	46
		Hover	24	10	-	-
		Go-around	2	5	14	12
		Autorotation	14	4	-	-
		Landing	26	23	50	36
		Other	4	2	-	3
Accident Contributory causes (% of total accidents) Note: Percentages sum to more than 100% due to multiple causes	Pilot Cause Factor	Spatial Misjudgment	51	32	56	46
		Failure To See Obstacle	29	80	19	65
		Misc. Factors	12	16	11	4
		All Other Causes		See Appendix A		
	Caused by other personnel	Supervisory Maintenance and Administrative	4	10	6	8
			2	7	2	-
	Pilot experience Pilot qualification	Less than 1 Year	70	60	69	67
		Nonrated	56	44	53	42
		Rotary-Wing Only	26	30		
		Fixed-Wing Only			31	42
	Physiological Factor	Unqualified Visual	30			
		Obstruction Dis-	28			
		orientation			25	
	Psychological Factor	Faulty Decision:				
		Flight Procedure	11		10	
		Use of Controls			12	
	Failed To Anticipate a Hazard		10			

*Percentages are rounded to nearest point

TABLE 6

TOTAL OBSTACLE STRIKES

Aircraft Class	TREE STRIKES						WIRE STRIKES					
	CARGO		UTILITY		OBSERVATION		CARGO		UTILITY		OBSERVATION	
Rotary Wing	CH-21	59	UH-1	58	OH-13	162	CH-21	17	UH-1	10	OH-13	113
	CH-34	66	UH-19	72	OH-23	71	CH-34	16	UH-19	15	OH-23	52
	CH-37	7					CH-37	0				
	CH-47	3					CH-47	1				
TOTALS R.W.		135		130		233		34		25		165
Fixed Wing	CV-2A-B	5	U-1A	7	O-1A&E	202	CV-2A	3	U-1A	2	O-1A&E	60
	C-126	2	U-6A	30	OV-1A	9			U-6A	7	OV-1A-B	4
			U-8DF	2					U-8F	2		
			U-9D	1					U-10	1		
			U-10	1								
TOTALS F.W.		7		41		211		3		12		64
TOTALS F. & R.		142		171		444		37		37		229

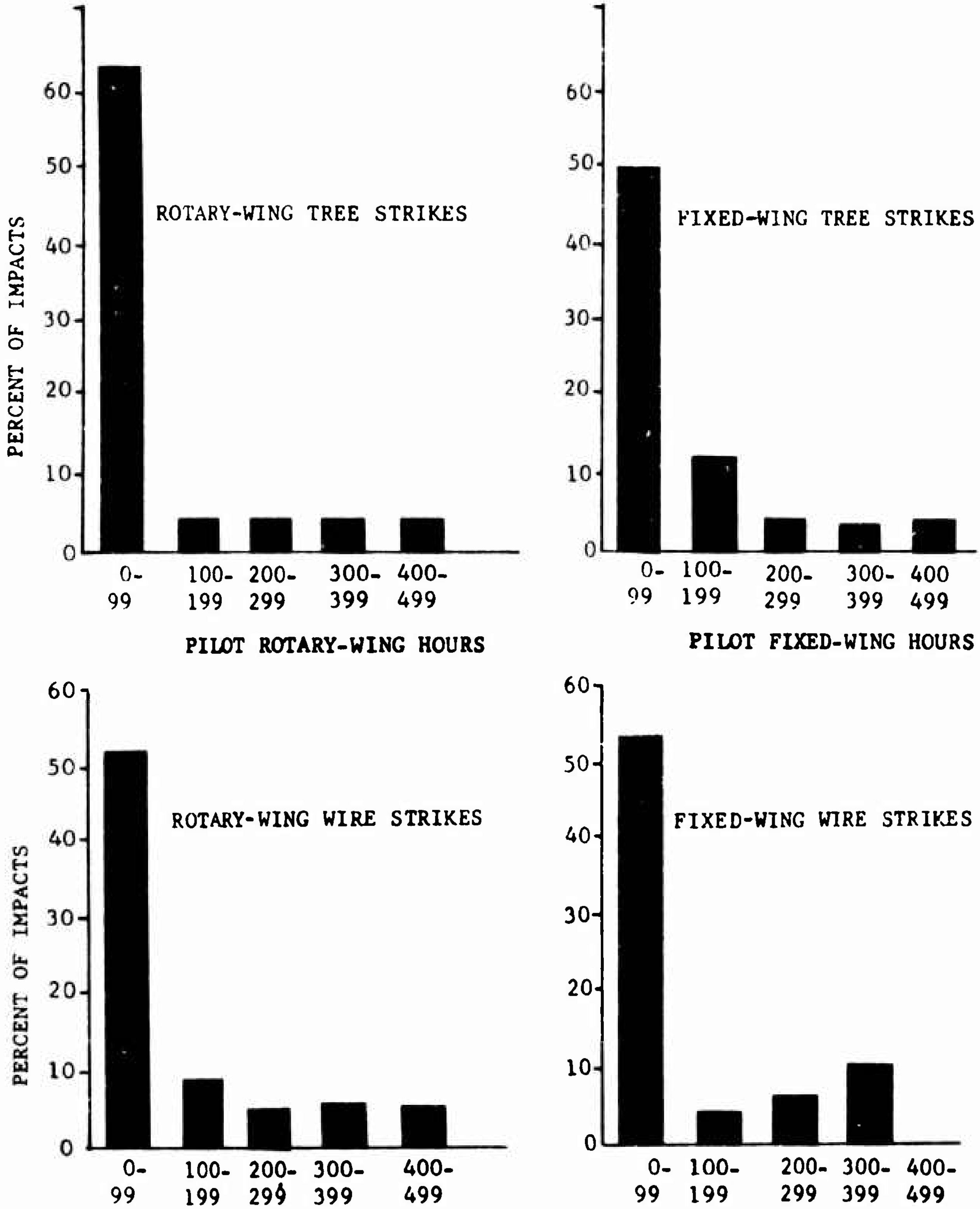


FIGURE 3. OBSTACLE STRIKES BY PILOT EXPERIENCE

are students and represent approximately 50 percent of the total accidents. Another contributing f-ctor, time in model, also relates pilot experience to accident rate and is presented in Figure 4. This figure illustrates the cumulative accident rate of the total pilot time in the aircraft model in which the mishap occurred. It will be noted that approximately 60 to 70 percent of the mishaps involved pilots with less than 10 hours of experience in that model aircraft - a very high rate. While obstacle strikes continue to occur with increasing familiarity with the model being flown, the percentage of total occurrences decrease significantly. The data indicate that these pilots are possibly being exposed to hazards beyond their capabilities early in their training. Extra transition time in the aircraft may provide the answer, although other unknown factors in the training program may be causative agents. It is realized that any restrictions placed on their training activities, while being newly indoctrinated, would adversely affect the training program. However, an average of only 2 percent of the total accidents involved pilots who had 10 to 20 hours experience in the aircraft model.

An area for improvement of flight safety may possibly be offered in an emphasized wire location program. Undoubtedly, standard safety procedures are followed to notify pilots of wire locations through NOTAM's and flagging methods. It may be possible to offer, through the flying safety officer, a "wire briefing" to alert pilots to wire danger in the area in which the mission is to be flown. Although the type of wire hazard is unknown, it is assumed that field communication wire is partly responsible. If this is true, measures should be taken to disseminate information regarding wire locations in the vicinity of possible operating areas.

Flight-hour information available included FY 1963, FY 1964, and the first half of FY 1965, not including combat operations. On the basis of these flight times, accident rates were determined per 100,000 flight hours and are tabulated in Table 7 by class and type of aircraft.

As noted previously, observation aircraft exceed all the others in gross numbers of accidents as well as in their strike rates involving wires. The accident rate for observation aircraft involving trees is exceeded only by the UH-19.

Differences in total strike rates between classes of aircraft, rotary versus fixed wing, indicate a rate for rotary-wing aircraft three times that of fixed-wing aircraft. Helicopters require a smaller turning radius, generally operate at much lower forward speeds, and often possess superior visibility. This apparent paradox in rates probably derives from the manner in which helicopters are employed. Operations from unprepared and unfamiliar areas might explain the higher incidence for rotary-wing aircraft. If training factors or design factors are involved, they cannot be deduced from the evidence available. The higher rates experienced by observation aircraft tend to support the environmental factor, since the missions of these aircraft are most likely to place them in forward areas away from normal facilities.

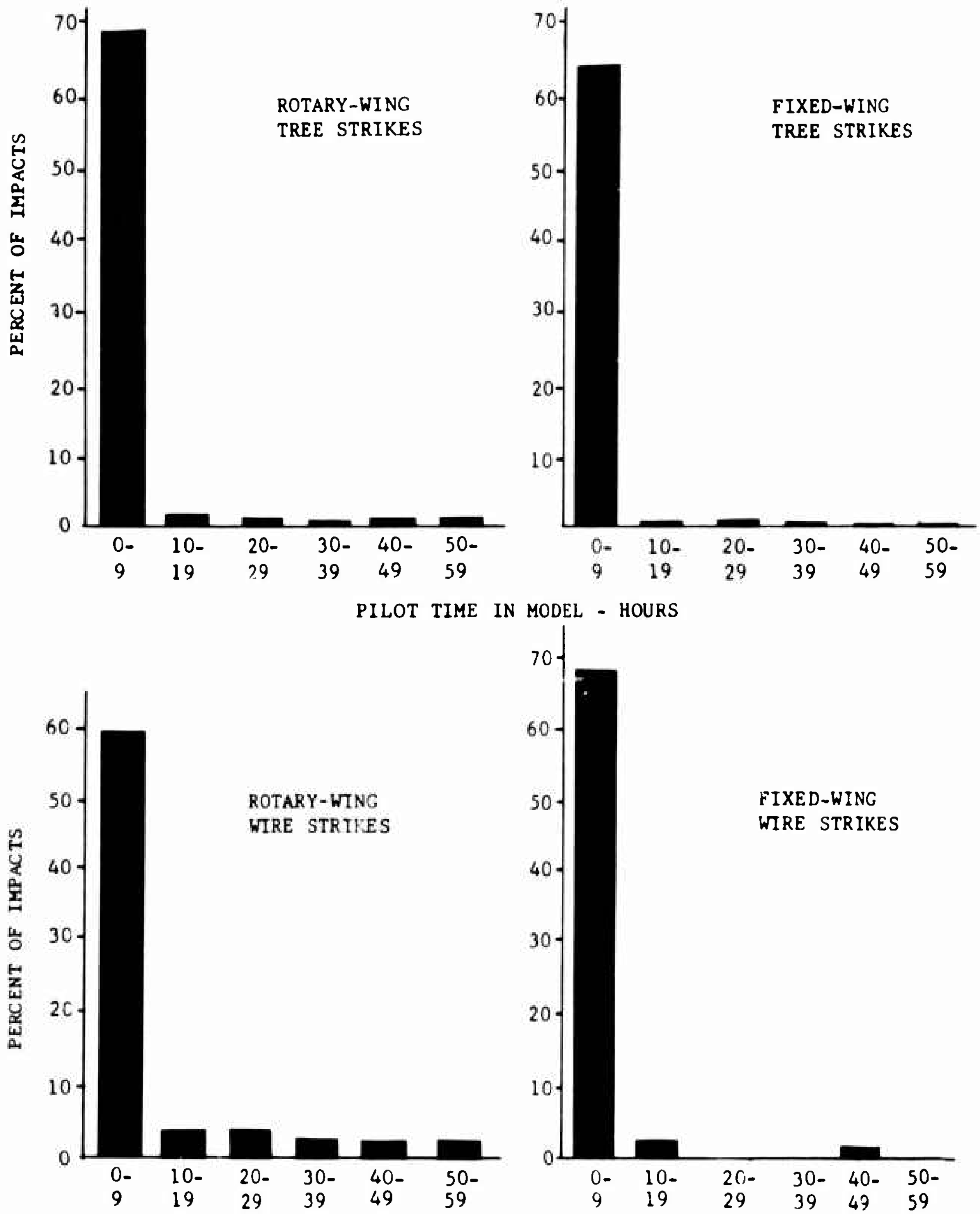


FIGURE 4. OBSTACLE STRIKES BY PILOT TIME IN MODEL

TABLE 7

AIRCRAFT OBSTACLE IMPACT RATE*
(IMPACTS PER 100,000 FLT. HRS.)

	AIRCRAFT MODEL	TREE STRIKES RATE	WIRE STRIKES RATE	TOTAL STRIKE RATE
		ROTARY WING		
UTILITY	UH-1	8.0	1.4	9.4
	UH-19	22.6	4.2	26.8
OBSERVATION	OH-13	16.5	10.1	26.6
	OH-23	4.3	4.2	8.5
CARGO	CH-21	8.8	4.4	13.2
	CH-34	12.6	1.5	14.1
	CH-37	0	0	0.0
	CH-47	0	0	0.0
		FIXED WING		
UTILITY	U-1	0.4	0.8	1.1
	U-6	1.2	0.3	1.5
OBSERVATION	O-1	5.2	1.8	7.0
	OV-1	5.2	5.2	10.4
CARGO	CV-2	1.5	3.1	4.6

*Accumulated over the period FY 1963, FY 1964, and first half of FY 1965 for noncombat operations of all Army aircraft.

In light of the foregoing, it appears that observation aircraft are the most likely candidates for consideration of obstacle sensor installations.

As noted in Table 7, observation aircraft show the highest or next to highest rates in all four categories of rotary- and fixed-wing tree and wire strikes. Fixed-wing aircraft rates are generally lower than those of rotary-wing aircraft for both tree and wire strikes. Of the fixed-wing models, the utility aircraft have the lowest rates for both tree and wire strikes; of the rotary-wing models, the cargo aircraft have the lowest rates in both classifications. The rotary-wing aircraft wire strike rates are lower than tree strike rates, but in the fixed-wing aircraft no distinction in rates is apparent.

OPERATIONAL PROCEDURES

A task analysis was accomplished relative to the procedures involving the operation of rotary-wing and fixed-wing aircraft in a low-altitude environment. In order that the task analysis cover only the critical areas of operation, obstacle strike statistics were reviewed to establish the particular phases of flight experiencing the highest proportion of obstacle strikes. Statistics established these phases to be takeoff, climb, descent, and landing for both rotary-wing and fixed-wing aircraft. Rotary-wing hovering flight was covered in the takeoff and landing phases. The obstacle strikes occurring in cruise flight were not considered in the analysis because of the small occurrence rate and because cockpit tasks were minimal. The task analysis investigated each operational procedure by reducing each task to subtasks, such as a simple throttle movement. The psychological and mechanical responses required to accomplish this subtask and its interfaces with other required tasks and subtasks were evaluated to determine their effects on the pilot's overall ability to operate the aircraft safely during certain phases of flight. The findings showed that aside from emergency procedures, the required procedures for low-altitude operations are typical for aircraft of this type and did not promote undue strain on the pilot.

Army aviation accident statistics indicated that over half of the obstacle strike occurrences involved nonrated pilots with under 100 hours of flying experience in both rotary- and fixed-wing aircraft. The high percentage of student pilots involved in these mishaps suggested a review of the training program. The investigation covered such specific training areas as low-level operations and tactics, along with pilot tasks associated with normal piloting functions such as takeoffs and landings.

The obstacle strike records received from the Army were statistically divided into tree strike and wire strike accidents. A quantitative review of cause factors determined that tree strikes are primarily caused by a lack of adequate operational judgment on the part of the pilot and that wire strike causes are mainly associated with the pilot's inability to see the obstacle in time to effect an evasive maneuver. This is not to imply

that other cause factors are not significant or important, but only to point out that the study confines itself to dealing with only the highest frequency cause factors associated with tree strikes and wire strikes. In fact, the highest frequency cause factor associated with tree strikes coincidentally becomes the second highest frequency cause factor of wire strikes, and vice versa. Therefore, the analysis, in effect, covered the primary and secondary problems associated with both rotary-wing and fixed-wing aircraft which represents over 50 percent of the obstacle strike problem.

Statistics for FY 1963 through the first half of FY 1965 have indicated a generally stable obstacle strike rate for rotary- and fixed-wing aircraft of approximately 7 per 100,000 hours for tree strikes and 3 per 100,000 hours for wire strikes. The constantly increasing emphasis on low-altitude operations versus the stabilized obstacle strike rate implies that some effective means of reducing obstacle strike occurrences is taking form in Army aviation. A more persistent effort in this area, on the part of staff and supervisory personnel, would inevitably yield lower obstacle strike rates.

An effective move on the part of the Army Aviation School was the interchanging of the instrument phase of training with the tactics phase. The present training syllabus now terminates with the instrument phase followed by the tactics phase. This action permits the student to become more proficient before exposing himself to the hazards of low-altitude flying; furthermore, it allows the student to leave training with a current exposure to the type of flying that would be required of him in actual operations.

Although the analysis has determined that the operational procedures are adequate, certain recommendations have been indirectly derived. These recommendations may be found in Section II.

IV. FORECAST OF OBSTACLE STRIKES

AIRCRAFT INVENTORY

To accomplish its present missions, the Army has in inventory approximately fourteen different types of aircraft. Based on this present aircraft inventory, a projection was made for the years 1970 to 1975. For this period, the total number of aircraft of both classes appears to be on the order of 9,160, as illustrated in Table 8. The estimates presented on the chart are taken from unclassified source documents as listed in the bibliography, References 16 and 17.

TABLE 8
FORECAST INVENTORY
OF ARMY AIRCRAFT
(1970 - 1975)

	ROTARY WING	FIXED WING
Observation	4000	260
Utility	1825	300
Cargo	430	340
Combat Support	1825	180
Totals	8080	1080

By the mid-1970 period, the number of different types of aircraft will be reduced to about nine, with further reductions in types forecast. This trend will, among other things, be helpful in reducing accidents, since greater proficiency in type (model) will be possible.

MISSION CATEGORIES

The mission categories within which the Army aviation accident statistics are recorded are training, administrative, test flight, combat, and other. Three major categories of operational missions may be listed as:

1. Reconnaissance, surveillance, observation

2. Transportation: cargo, personnel

3. Combat support

All of these missions involve low-altitude flight in a combat zone. Observation and surveillance missions usually require a major portion of the flight to be at low altitude, as do ground fire suppression missions. Combat support missions require delivery of personnel and equipment into areas that are restricted in size, unprepared, and often unfamiliar to the pilot.

Coupled with the foregoing mission requirements are the complicating factors of reduced visibility resulting from dust, burned grasses, ground haze, and other obscurations that would be generated by a large flight of aircraft hovering, landing, and taking off from unprepared surfaces. Maneuver space is usually limited because of the proximity of other aircraft, and mid-air collision is an ever-present danger. The resultant environment exposes Army aviation operations to more danger of striking ground obstacles than any other type of military flying.

ANNUAL OBSTACLE STRIKES

Based on the postulated forecast of Army aircraft inventories and assuming continued use of present standing operating procedures, an expected annual occurrence of tree and wire strikes may be predicted. Figure 5 shows the expected annual rate of rotary-wing tree and wire strikes as a function of aircraft utilization. The curves of Figure 5 are based on the 1970 - 1975 inventory estimates of the four types of aircraft noted. Since utilization of the different aircraft can vary so widely, the expected impacts were calculated for a range of aircraft utilization. The current emphasis on low-altitude flight in Southeast Asia suggests an increase in the proportion of low-altitude flight time; consequently, a concomitant increase in the rate of obstacle impacts per flight hour may be anticipated. However, the increased rate may be partially offset by experience and improved operational techniques.

Based on the data in Reference 1, the average utilization rates for the different types of aircraft are forecast in Table 9:

TABLE 9
FORECAST AIRCRAFT UTILIZATION

	FIXED WING	ROTARY WING
Utility	30 - 40 hr/mo	30 - 35 hr/mo
Observation	20 - 35 hr/mo	15 - 25 hr/mo
Cargo	60 - 65 hr/mo	15 - 25 hr/mo
Combat Support	20 - 40 hr/mo	15 - 35 hr/mo

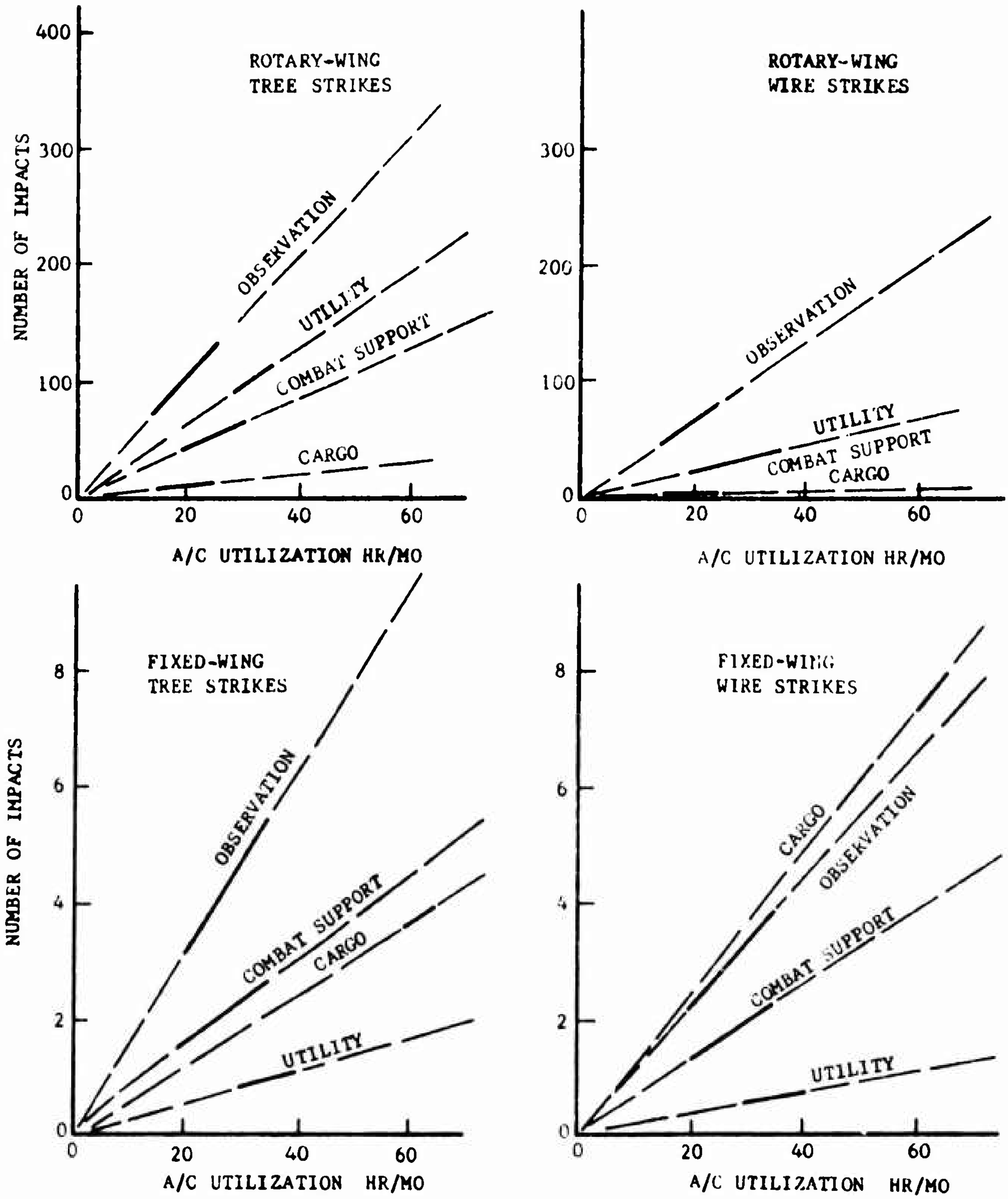


FIGURE 5 OBSTACLE IMPACTS ANNUAL RATE 1970-75 FORECAST

Analysis of the statistics regarding accident class gives the distributions for the various types of aircraft as shown on Tables 14 and 15 for fixed-wing and rotary-wing aircraft, respectively. Since the greatest loss involves the classes "Substantial Damage" and "Totally Destroyed," these are assumed to constitute the bulk of the problem of tree and wire strikes. A quantitative evaluation is reached by considering the probability of substantial damage or total loss for the different types of aircraft in each of the accident categories. The predicted distribution of aircraft losses is shown on Table 10.

The preponderance of rotary-wing aircraft in the projected inventory, with their higher expected degree of damage, shows that major effort should be directed toward solving the problems of rotary-wing tree strikes and wire strikes. More than 40 percent of the forecast losses involve observation aircraft, which are characteristically small and have severe weight and volume limitations for accommodating installation of sensor equipment.

The conditions listed below summarize the nature of the expected obstacle strikes in the 1970 - 1975 time period projected on the basis of recent experience:

1. 60 percent would be rotary-wing tree strikes and 30 percent rotary-wing wire strikes.

2. 70 percent would involve student pilots or newly rated pilots.

3. Pilot cause factors are primarily errors in judgment of speed, altitude, or position, or in failure to see the obstacle.

TABLE 10

FORECASTED ARMY AIRCRAFT LOSSES
(1970 - 1975)

	ROTARY WING			FIXED WING		
	Expected No. Impacts **	Probability of Major Damage or Total Loss *	Expected No. of Aircraft Lost	Expected No. Impacts	Probability of Major Damage or Total Loss *	Expected No. of Aircraft Lost
Tree Strikes						
Observation A/C	105	.38	40	4.1	.35	1.4
Utility A/C	105	.28	29	2.1	.68	1.4
Combat Support A/C	55	.35	19	0.9	.50	0.5
Cargo A/C	8	.48	4	3.9	.08	0.3
Total A/C Lost by Tree Strikes			92			3.6
% of Total A/C Lost			62%			2.5%
Wire Strikes						
Observation A/C	65	.35	23	2.9	.13	0.4
Utility A/C	36	.43	15	0.6	.40	0.2
Combat Support A/C	30	.40	12	1.7	.25	0.4
Cargo A/C	5	.25	1	7.7	.02	0.1
Total A/C Lost by Wire Strikes			51			1.1
% of Total A/C Lost			34.5%			1%

Total A/C Lost = 147.7

*Based on recent experience

**Based on inventory in Table 8, the impact rates in Figure 5, and the forecasted utilization rate shown on Table 9.

V. EQUIPMENT/PROCEDURES CONCEPTS TO ALLEVIATE HAZARDS

Three general system concepts were investigated as feasible solutions to the problems of low-altitude obstacle impacts: a landing aid or glide slope device; the installation of a trained observer on low-altitude missions to detect obstacle hazards; a radar sensor with a computer, a sensor alignment device, and an automatic warning device. These concepts are discussed in the following paragraphs. In the third concept, five different types of sensors were examined: two active and three passive. The active sensors, millimeter radar and optical radar, appear to be promising, but the passive sensors were found to be inadequate. These passive systems are discussed briefly in the text, and the detailed evaluation is presented in Appendix II.

LANDING AID

The statistics show that approximately 25 percent of the rotary-wing obstacle impacts and 50 percent of the fixed-wing obstacle impacts occur during the landing phase of aircraft operation. Therefore, a simplified landing aid or glide slope device is considered as a low-cost partial solution to the problem. The systems discussed below are immediately available or close to being operationally available.

Honeywell Inc. has developed a system which defines a landing glide slope by means of an electronic beam. Reference 3 states that the equipment consists of a ground station transmitter, an airborne receiver, and a cross-point indicator cockpit display. Flight testing of the equipment has indicated that a signal can be received at a range of approximately 15 miles. The glide slope can be adjusted up or down to insure clearance of obstacles along the flight path. The pilot can keep the aircraft on the specified glide slope within half a degree of elevation and within two degrees of azimuth. Ground power may be obtained from a 28-volt aircraft battery.

An optical landing aid called "Rainbow" has been developed by the U.S. Naval Research Laboratory. Reference 4 states that the Rainbow system provides accurate glide slope definition to the pilot. It gives a color-coded signal to indicate whether he is above, on, or below the proper glide slope. The signal is visible from as far away as 3½ miles in bright daylight, and considerably farther at night. The unit is contained in a single package except for power supply, which is estimated as one kilowatt.

The U.S. Navy mirror landing system is available as a portable unit which would be mounted on the edge of the landing strip. The technique of using the system is readily learned, and it accurately defines a glide slope in a manner similar to the other glide slope systems. The power requirement is expected to be less than two kilowatts for a visual range of approximately three miles.

TRAINED OBSERVER

The second general concept considered as a solution to the problem of low-altitude obstacle avoidance is the assignment of the copilot to observing and warning the pilot of potential hazards. If this is not possible, some other member of the crew might act as an observer during critical phases. The addition of observers can best be evaluated in terms of the tradeoff between increase in probability of detection and decrease in useful load.

The probability that a single observer will detect an obstacle can be estimated on the basis of the observer's characteristics, the aircraft, the time of day, visibility conditions, and the characteristics of the terrain. The increase in the probability of obstacle detection resulting from the use of a second observer is obtained by the equation.

$$INCR = \frac{P_{1+2} - P_1}{P_1}$$

where P_1 is the probability of obstacle detection by a single observer and P_{1+2} is the probability of obstacle detection by a combination of two observers. If the two observers have the same capability, then

$$P_{1+2} = 1 - (1 - P_1)^2;$$

if their capabilities differ, then

$$P_{1+2} = 1 - (1-P_1)(1-P_2).$$

Observer stations should be easy to install on larger helicopters, but the copilot would have the observer responsibility on the smaller observation aircraft. Installation of a plastic dome or blister at suitable locations on the fuselage to allow the observer the same field of view as the pilot would be one solution.

The suggestion of adding an observer does not necessarily imply that each aircraft would be so equipped, except when operating independently. Using the lead aircraft in each flight element or a single aircraft as a pathfinder might well serve the purpose intended. Visual aids, such as field glasses, could also be employed to assist in early hazard detection. Since such techniques are already utilized in reconnaissance and observation flights, they could be readily adaptable to the other mission categories of transport and combat support.

Further illustration of the use of a crew member as a sensor system is shown in Table 11 and Figure 6. The table shows the percentage increase in probability of detection when an observer is added to assist the pilot in the search or scanning function. This might be the case when comparing a pilot and observer searching the same area. If the observer is other than the copilot, he must be given a suitable observation station;

TABLE 11

PROBABILITY OF OBSTACLE DETECTION BY ONE OR TWO OBSERVERS

ONE OBSERVER	TWO OBSERVERS*	PERCENT INCREASE
.10	.19	90
.20	.36	80
.40	.64	60
.60	.84	40
.80	.96	20
.90	.99	10

* Probability of obstacle detection is the same for each of the observers.

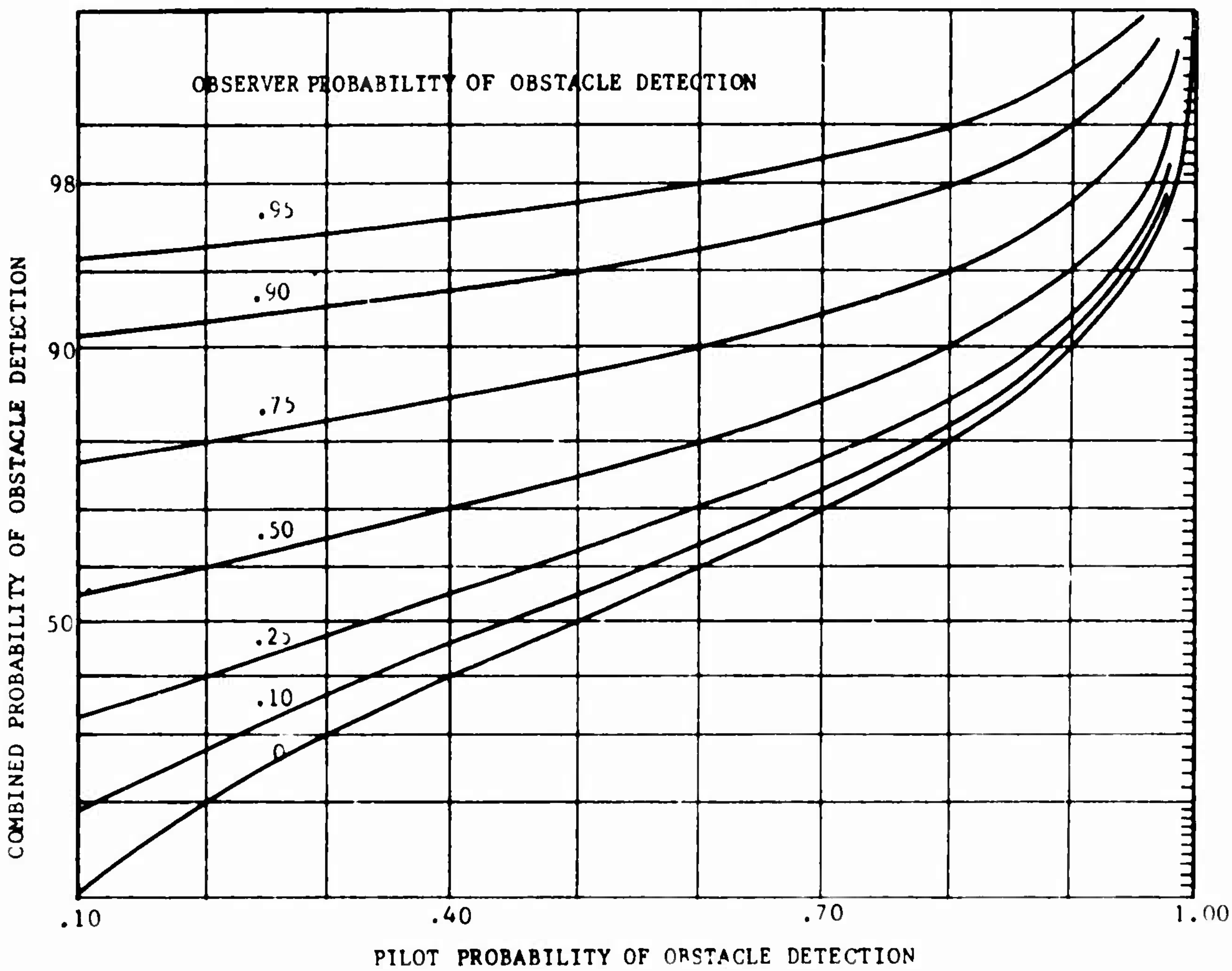


FIGURE 6. PROBABILITY OF DETECTING OBSTACLES VISUALLY

otherwise, his capability will be too limited and his motivation seve 'y reduced. This bias could nullify the benefits of an added observer. an adequate viewing station is provided, a trained observer could be more effective than the pilot. This would make the combined probability of detection even higher than shown in the table. Training would be required to develop proper techniques, duties, and responsibilities.

Figure 6 is a graphical presentation of the combined probability of detection for a range of pilot and observer detection capabilities. It shows that the higher the pilot's detection capability, the less capability gained by an added observer.

RADAR OBSTACLE-AVOIDANCE SYSTEM

The radar obstacle-avoidance system concept consists of a radar, an inertial platform, an integrator, and a coordinate converter, as shown in Figure 7. The accelerometers of the inertial platform produce signals of longitudinal, lateral, and vertical acceleration to be integrated in the integrator to obtain inertial components of velocity. These signals, plus indications of aircraft attitude and rotational rates, supplied from the inertial platform, are then supplied to the coordinate converter. The coordinate converter converts the aircraft velocity components from inertial platform coordinates into aircraft coordinates. These signals, representative of aircraft velocity components, are then utilized by a gimbal and drive system to aim the sensor about the true velocity vector of the aircraft.

For each aircraft, there will be a different required angular scan coverage to guarantee adequate time for accomplishing the avoidance of an obstacle. The sensor scan programmer can be varied to supply the optimum field of view for any given aircraft that may use the obstacle-avoidance system.

Fixed-wing aircraft, with propellors cutting across the sensor field of view, require synchronization of the radar pulses with the propellor blades. The radar return from the propellor could be sufficient to damage the receiver unless the system is specifically designed to accommodate it.

The requirements for a radar obstacle-avoidance system are developed considering the problems described earlier in this report. Conditions that must be satisfied are:

1. Detection and warning of obstacles at ranges adequate for response and avoidance maneuver.

2. Operational in both fixed- and rotary-wing aircraft.

3. Usable by student pilots in the training environment.

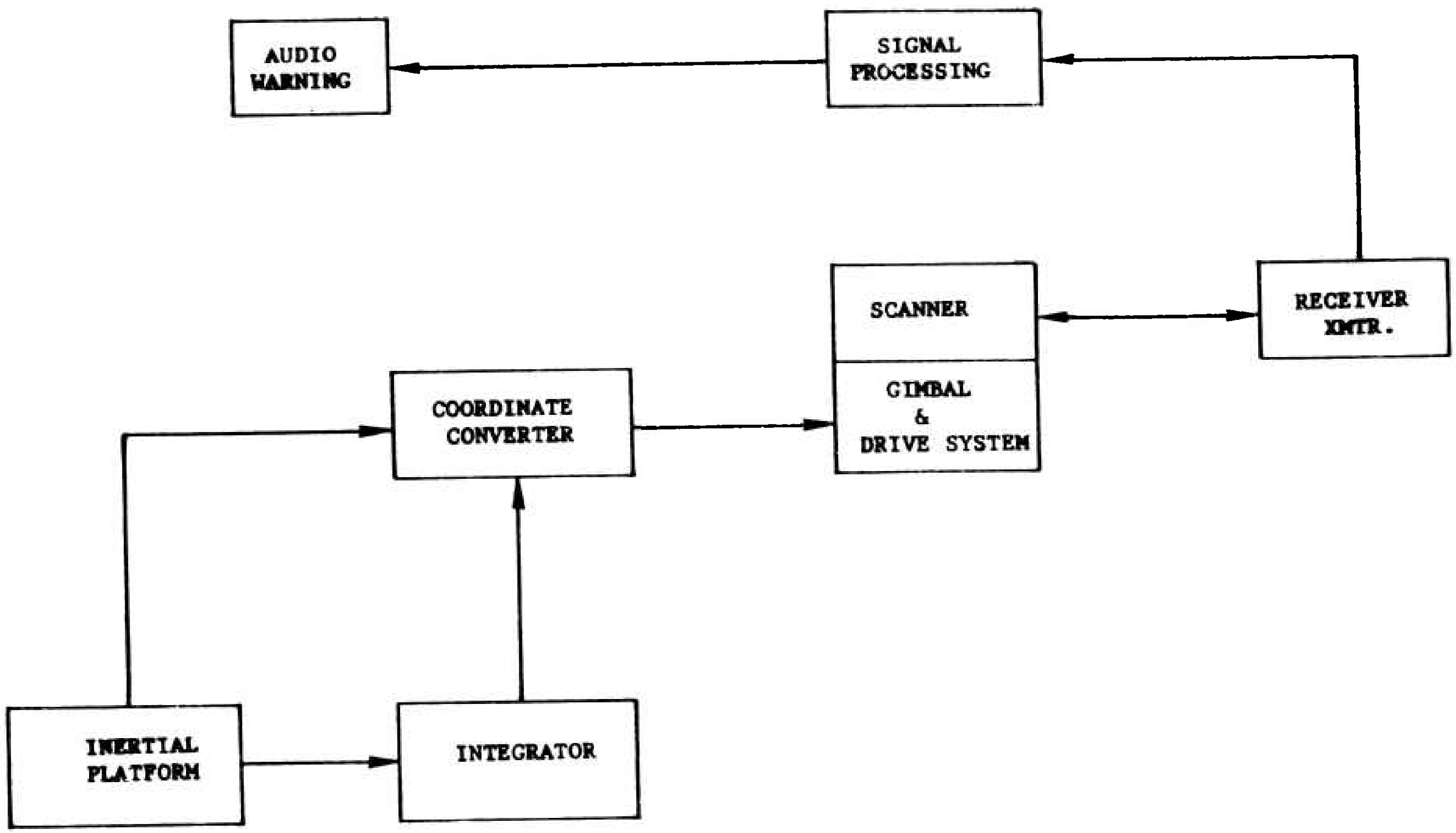


FIGURE 7. RADAR SYSTEM BLOCK DIAGRAM

Sensors Investigated

Sensor capabilities of the following systems have been investigated:

1. Millimeter radar
2. Optical radar
3. Microwave radiometer
4. Infrared
5. Electro-optical

Sensor Requirements

Detection Range

Required detection range is defined to be that minimum distance after which the pilot can respond and maneuver the aircraft laterally to miss the detected obstacle. As noted previously, the maneuver is not restricted to the horizontal plane. The turn radius is calculated for the horizontal turn and is assumed to be the same whether the turn is horizontal, vertical, or anything in between. The obstacle is taken to be a point, and a lateral maneuver of one-half the span of the aircraft is assumed sufficient for clearance. Detection range is determined by three basic factors: (1) the turning performance of the aircraft, (2) the pilot's response or reaction time, and (3) the aircraft response to the controls, as shown on Figure 8. The turning radii of the various types and models of aircraft were used to establish the turning distance as a function of aircraft speed. Reference 5 shows that the pilot reaction time may be 3 or 4 seconds and that aircraft response time for transition from straight and level flight to a maximum capability turn may be 2 to 4 seconds. The combined reaction time is then 5 to 8 seconds. However, the combined pilot-aircraft reaction time was varied parametrically in this analysis from 0 to 9 seconds as shown on Figure 9. Since the turning time is short compared to the pilot-aircraft reaction time, the required detection range is almost a linear function of aircraft velocity. The rotary-wing aircraft are in the band below 150 knots, while the fixed-wing aircraft fall between 65 and 275 knots. The bands shown on Figure 9 encompass the variations in detection range due to the maximum velocity and maneuver capabilities of the different aircraft.

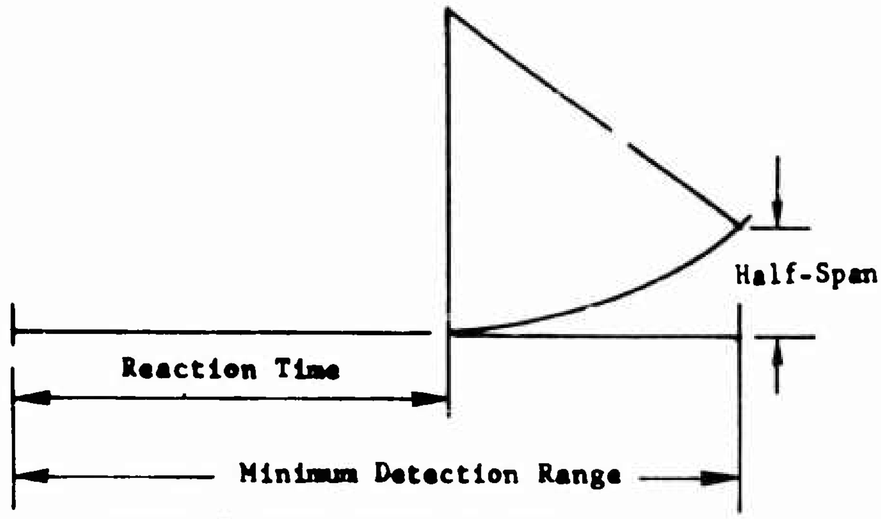


FIGURE 8. VARIATIONS IN DETECTION RANGE
The aircraft is assumed to be moving at maximum velocity, and the turn is accomplished at maximum allowable load factor.

Sensor Field of View

In determining the required size of the field of view, flight path deviations due to gusts and other factors must be considered as well as the view required for an avoidance maneuver. The flight path perturbations caused by wind gusts and pilot control movements result in fluctuations about the mean aircraft heading up to 3 degrees.

Figure 10 shows the effect of gusts on the angular displacement of the OV-1A Mohawk at sea level. Angular displacement is inversely proportional to aircraft velocity as shown by the difference between Mach .2 and Mach .4 (132 - 264 knots). The curves indicate that there is no significant difference between pitch and yaw displacements. At 132 knots, the aircraft encounters ½ degree displacement rotations 8 times per mile; and 1 degree or greater rotations occur, on the average, 4 times in a mile. On the basis of these curves, it is estimated that a 1-degree allowance for gusts is compatible with pilot capability and minimizes requirements imposed on an obstacle detection system.

Discussions with Army aviation personnel at Fort Rucker indicated that rotary-wing aircraft are less affected by gusts than are fixed-wing aircraft. However, since an objective evaluation is not available, the effects shown for the OV-1 are taken as typical for all Army aircraft. The acquisition of more accurate data in the future may constitute a basis for evaluating various aircraft types, but the magnitude of the rotation angles shown compared to the field of view angles indicates that the refined calculations would show only a second-order effect.

The field of view required for the avoidance maneuver is a function

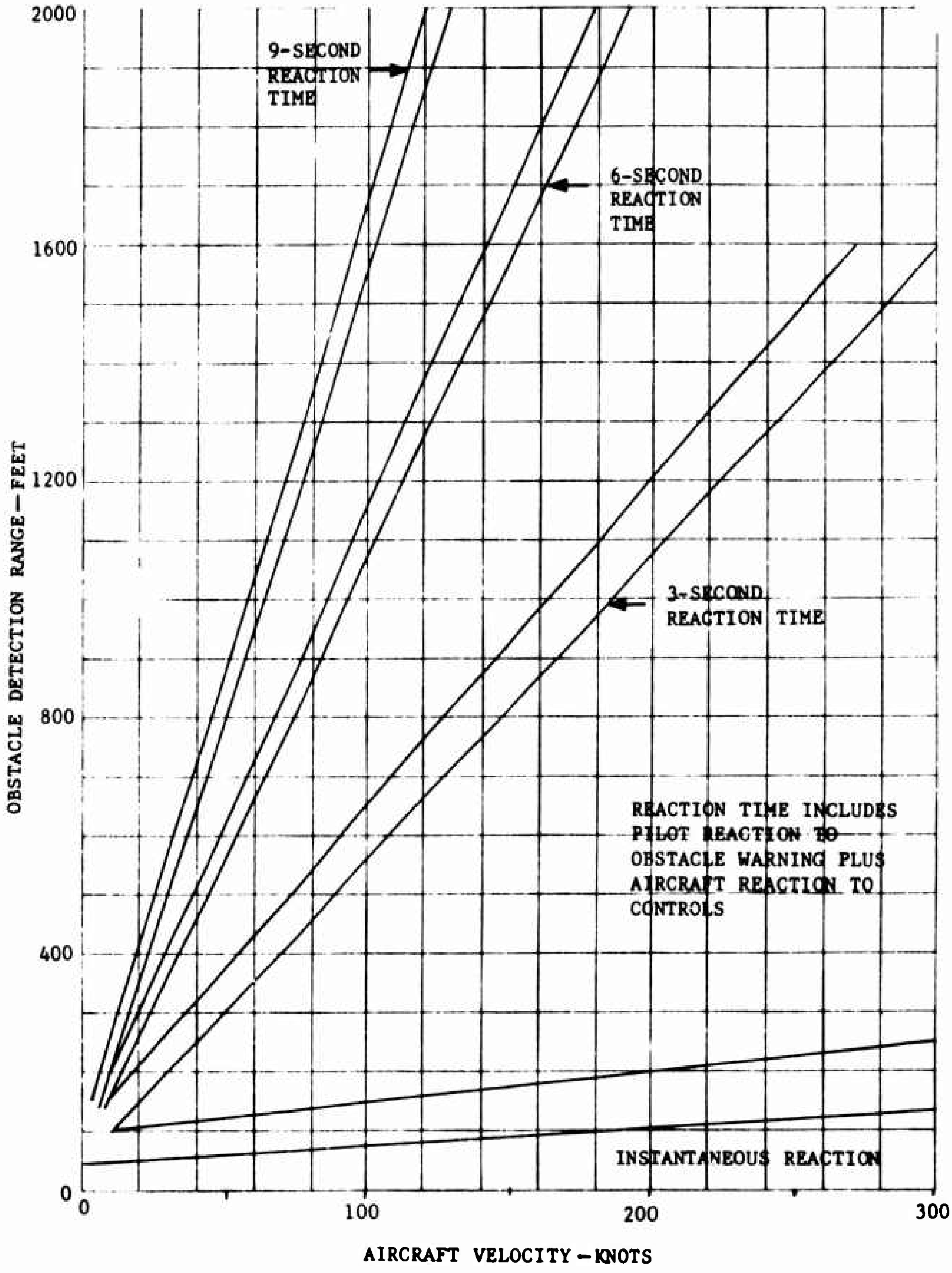


FIGURE 9. OBSTACLE AVOIDANCE DETECTION RANGE

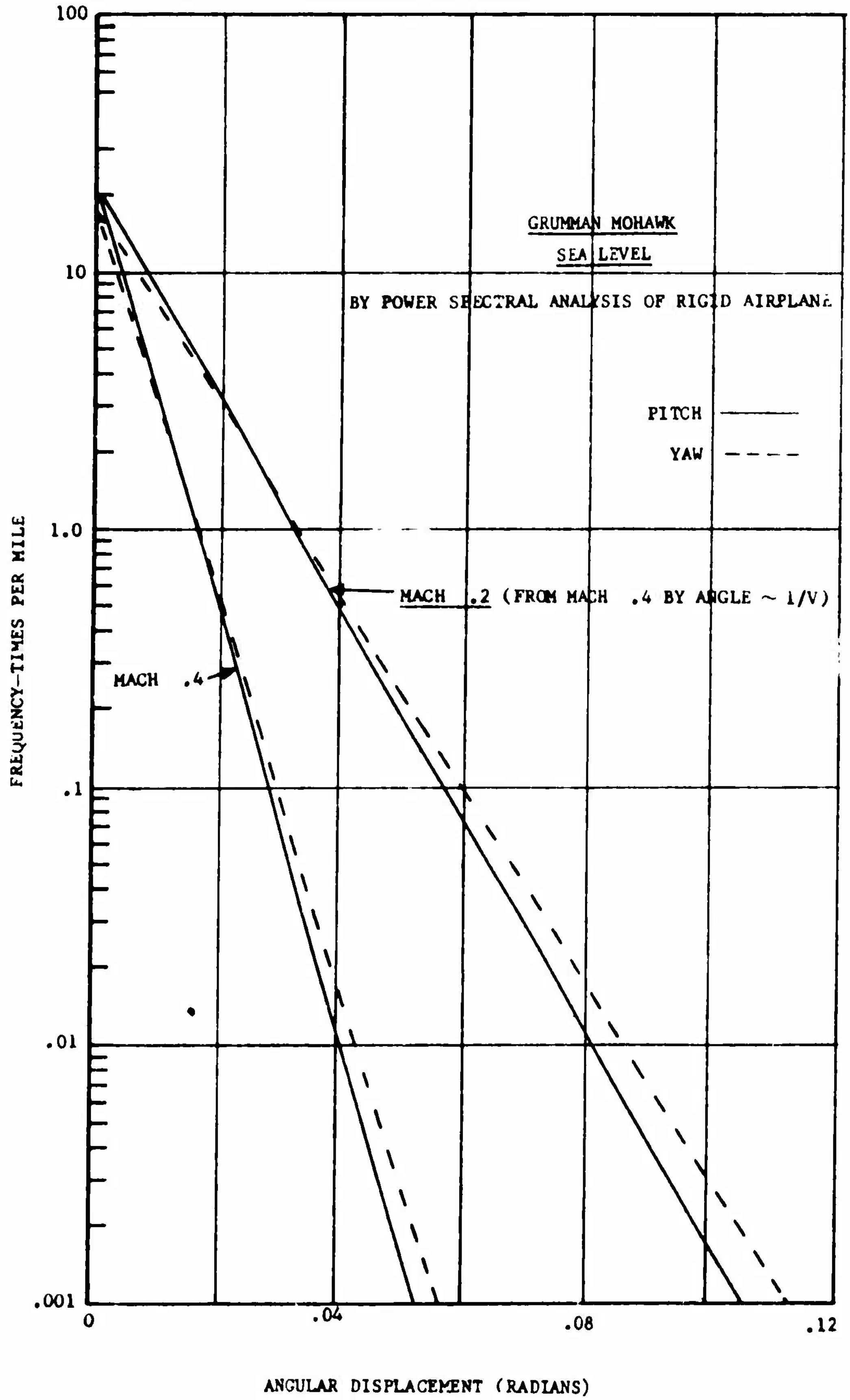


FIGURE 10. AVERAGE NUMBER OF TIMES PER MILE ANGULAR DISPLACEMENT IS EXCEEDED

of the detection range. This required field of view is defined by

$$\alpha = 2 \sin^{-1} \left[\frac{\text{Semi-Span}}{\text{Detection Range}} \right].$$

Table 12 contains the minimum size of the field of view required for maneuver of the various aircraft. As noted previously, the required field of view expands as the aircraft velocity is reduced. The field of view at maximum aircraft velocity, from Table 12, is 1½ to 3 degrees. With these small angles, the reduction of the aircraft velocity to one-half the maximum approximately doubles the required field of view, namely, 3 to 6 degrees.

The landing velocity of the fixed-wing aircraft is one-third to one-half the maximum speed. Therefore, the field of view required for landing is two to three times that of maximum velocity, and the detection range requirement is correspondingly reduced.

Some of the slower or more maneuverable aircraft, particularly rotary-wing vehicles, require up to a 10-degree field of view to meet the requirements discussed above. At velocities below 40 knots, the required field of view expands so rapidly as to constitute completely different operating conditions for an obstacle sensor.

Since these requirements of detection range and view angle are related to ground speed rather than air speed, a doppler measure could be used to adapt range gate and scan pattern to the actual aircraft ground speed. Limitations on the size of the field of view are required to prevent excessive false alarms, and yet the field of view must be large enough to accommodate momentary pitch and yaw fluctuations of the aircraft without losing sight of the obstacle.

The field of view should be wide enough in azimuth to insure clearance between the obstacle and the wing tip (or rotor tip), and should extend in elevation to insure clearance between the obstacle and the lowest portion of the aircraft. The lowest portion may be the landing gear, the empennage, or the tail rotor, depending on the attitude of the aircraft; and the field of view must be designed so as to give full consideration to the aircraft contours presented.

The field of view and detection range requirements for straight-line flight are described in a prior section of this report. Consideration of a constant-speed turn shows that the field of view must be elongated in the plane of the maneuver in accordance with the aircraft speed and turning radius. A constant-speed turn requires at least double the field of view, and a decelerated turn probably doubles again the required field of view, with a corresponding degradation of system resolution. Study of various flight paths shows that a very small portion of almost any flight

TABLE 12

FIELD OF VIEW REQUIRED AT MAXIMUM AIRCRAFT VELOCITY
ALLOWING 6-SECOND REACTION

	DETECTION RANGE (FEET)	MAX SPEED (KNOTS)	SEMI-SPAN (FEET)	MINIMUM FIELD OF VIEW (DEGREES)
O-1	1110	98	18	2
U-1	1500	137	29	2-1/4
U-8	2160	203	23	1-1/4
CV-2	2060	185	48	2-2/3
OV-1	2600	275	21	1
OH-6	1410	125	13	1
OH-13	910	91	18-1/2	2-1/3
OH-23	730	83	18	2-3/4
UH-1	1310	118	24	2
CH-21	1350	120	22	2
CH-34	1120	105	28	3
CH-47	1640	150	30	2

is involved in extensive maneuvering, particularly at low altitude. Therefore, the problems and complications of an obstacle-warning system capable of predicting a curved flight path are considered prohibitive at this time, and the analytic effort is confined to the dominant straight-line flight regime.

Rotary-wing aircraft have the capability of moving laterally or even of reversing, with the attendant complications of system requirements of sensor alignment and field of view. 25 percent of the tree strikes and 10 percent of the wire strikes occur during hover, most of which were attributed to pilot errors in judgment. These pilot judgment errors may be more readily corrected by education than by some electronic device, which would be significantly more complex than those systems proposed for detection of obstacles while in forward flight. Additional, extensive study and analysis are required to develop feasible system concepts capable of meeting aircraft maneuvering and hovering requirements.

Sensor Techniques

Millimeter Radar

A 70,000-megacycle radar was investigated to determine its suitability as an obstacle-detection system for low-altitude flight. The most critical obstacle, from a detection standpoint, is a 1/8-inch-diameter wire. The detection range and field of view required have been defined previously, and the radar parameters are:

F = Frequency = 70 GC (λ = .43 cent.)

P = Peak Power Out = 500 watts

G = Antenna Gain = 54 db (3-foot dish) and 45 db (1-foot dish)

μ = Pulsewidth = 20 nanoseconds

PRF = Pulse Repetition Frequency = 2,000 Pulses per Second (PPS)

Δf = Receiver Bandwidth = 50 megacycles

$\overline{NF}$ = Receiver Noise Figure = 11 db

The equation used to calculate detection range of the obstacle was taken from Reference 5:

$$R = \sqrt[4]{\frac{G^2 \lambda^2 P \sigma}{\Delta f \ \overline{NF}}}$$

where

R = Detection range in nautical miles

G = Antenna gain as a power ratio

λ = Wavelength in centimeters

P = Peak power out in watts

Δf = Receiver bandwidth in megacycles

$\overline{NF}$ = Receiver noise figure in power ratio

σ = Radar echo area in square meters

The ranges calculated are displayed in Figure 11. Radar echo area was calculated by first utilizing the two following equations for References 6 and 7:

$$\sigma = \frac{2\pi L^2 a}{\lambda} \tag{1}$$

where

L = Length of wire (assumed to be 6 feet for calculations)

a = Radius of wire

λ = Wavelength

and

$$\sigma = \frac{a\lambda \cos\phi \sin^2 \frac{2\pi L}{\lambda} \sin\phi}{2 \sin^2\phi} \tag{2}$$

where

ϕ = Illumination angle measured from broadside

Equation (1) was used to calculate only when $\phi = 0°$.

The calculated radar echo areas for the 1/8-inch and 1-inch cables are shown on Figure 12.

In calculating the ranges shown on Figure 11, the σ used was an average of the radar echo areas. The average excluded the echo areas at $\phi = 0°$ and $\phi = 90°$ because the change in radar echo near the $\phi = 0°$ is so rapid that its inclusion in the calculations would give unrealistic results. At

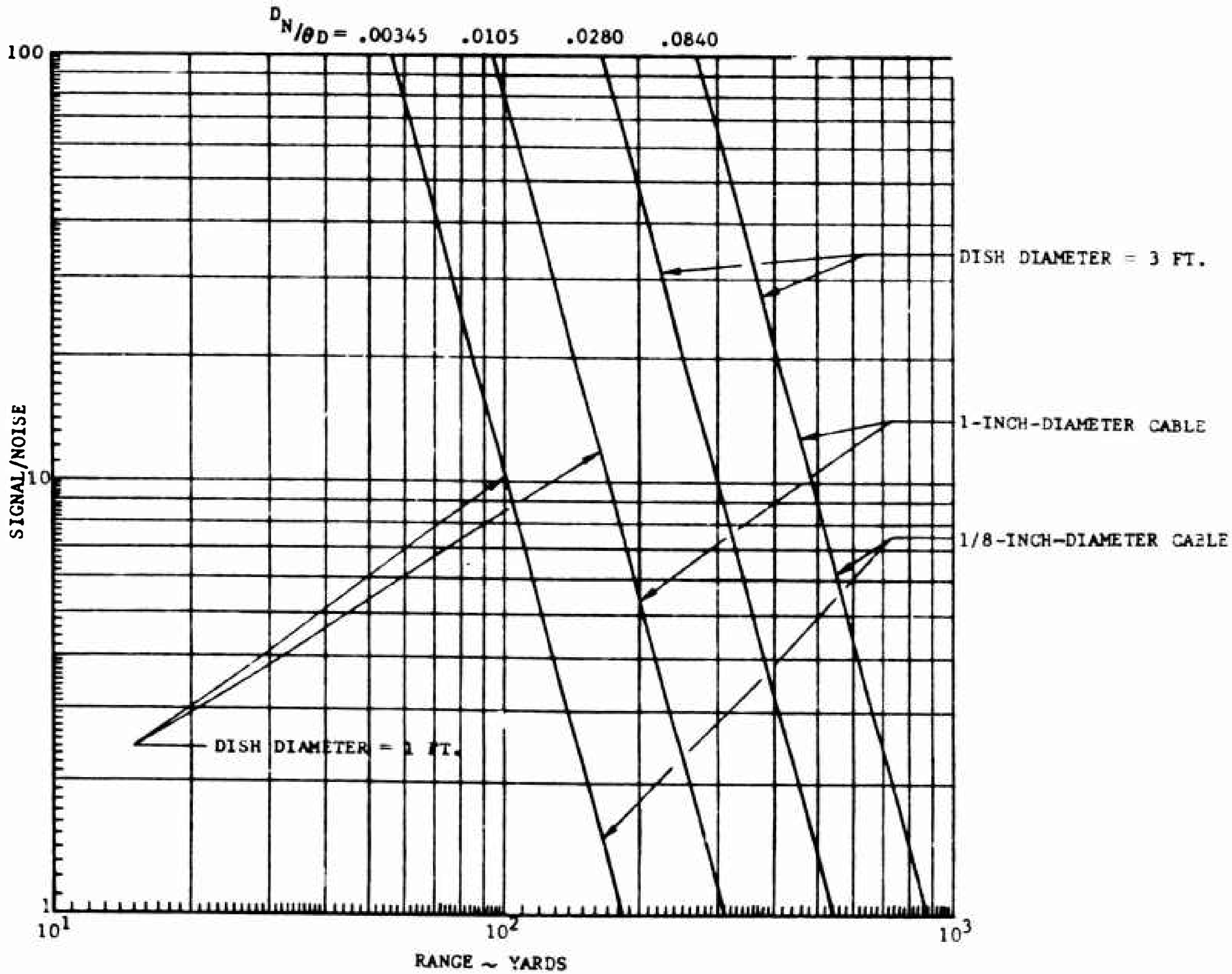


FIGURE 11. WIRE DETECTION WITH MILLIMETER RADAR

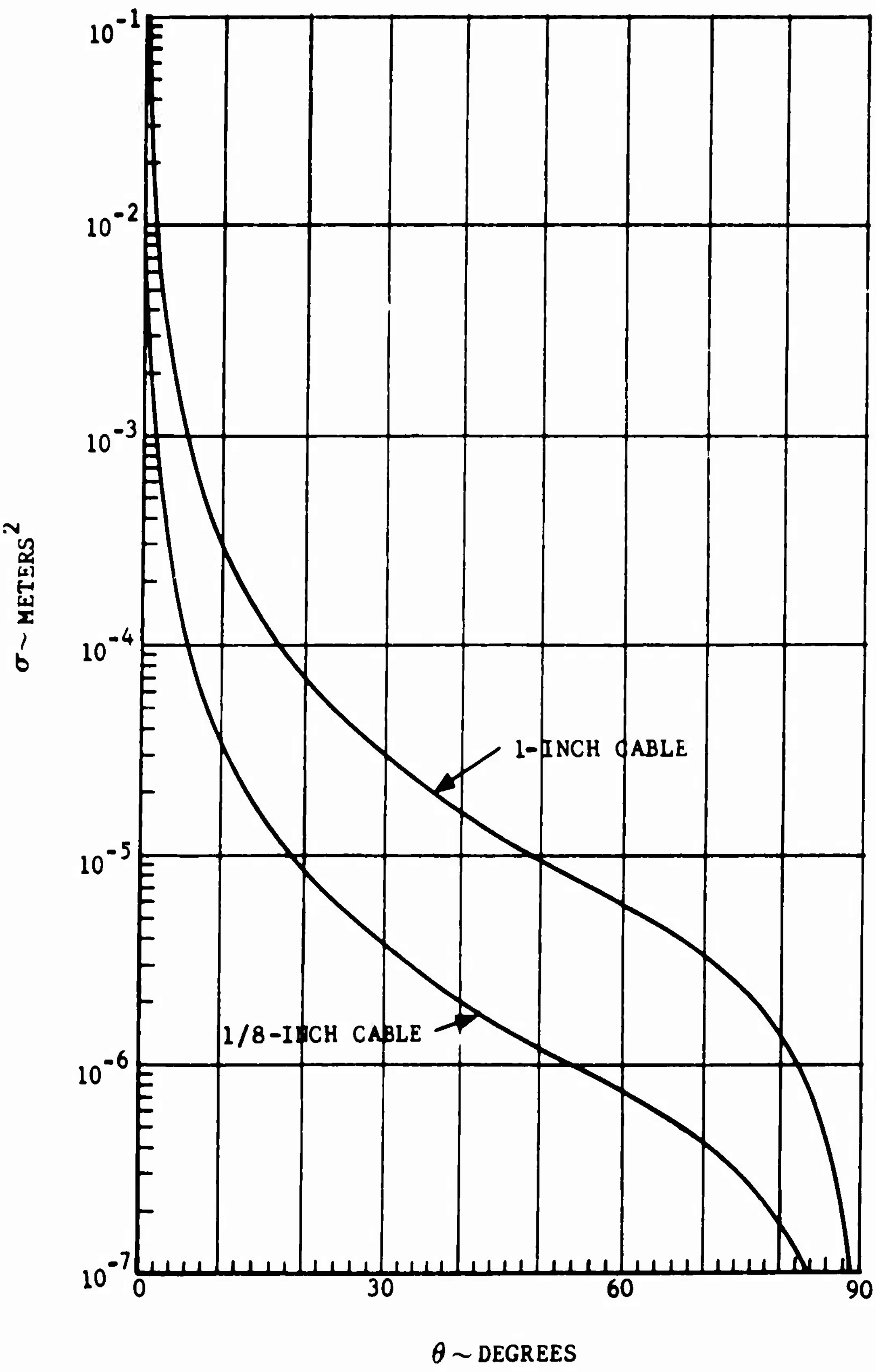


FIGURE 12. RADAR ECHO AREA OF WIRE

$\phi = 90°$, the echo area approaches infinity.

No systems losses were included in the calculations, but the high number of pulses of the radar (with a PRF of 2,000 PPS or better) would increase the detection range.

There are some radar capabilities that may be utilized to enhance detection of the various obstacles, one of which is to use dual (simultaneous horizontal and vertical) or circular polarization.

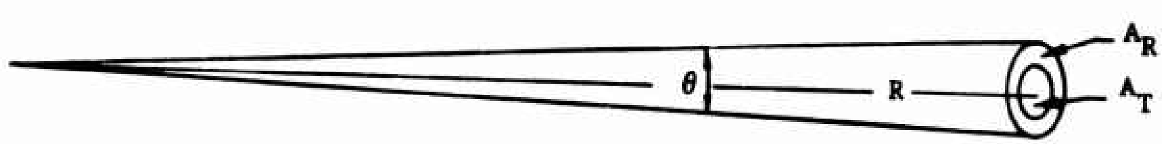
Detection curves for the millimeter radar do not consider the requirement for scanning; but the radar is capable of a very high PRF, and consequently a high data rate is possible with the small required field-of-view sector.

A study was initiated to determine the problem of return from the side lobe which is 1.6 degrees down from the main lobe for the millimeter radar with the 1-foot-diameter dish. During level flight at a 100-foot altitude, the return from earth due to the first side lobe would have to be greater than 80 decibels above the return from an obstacle 1,000 feet away to obscure it completely.

Because of the high frequency (70,000 megacycles) of the radar, the main beam is very narrow and the side lobes are very close to the main beam. This factor plus the capability of gating out any return beyond the required detection range should reduce the effect of extraneous return from the side lobe to the point where it is not a problem.

Optical Radar

An optical radar system's capability as an obstacle-detection device was evaluated per Reference 9. The effect of changing the noise equivalent power (NEP) on the detection range of 1/8-inch wire and 1-inch cable is shown on Figure 13. The estimated signal-to-noise ratio that can be obtained with the present state of the art is approximately six. Therefore, the range at which the small wire can be detected is 230 yards for NEP = 10^{-9} and is 2,700 yards with NEP = 10^{-12}. The method used for calculating radar range is presented below.



Derivation of Laser Ranging Equation
(Reference 10)

θ = Beamwidth

R = Range to Target

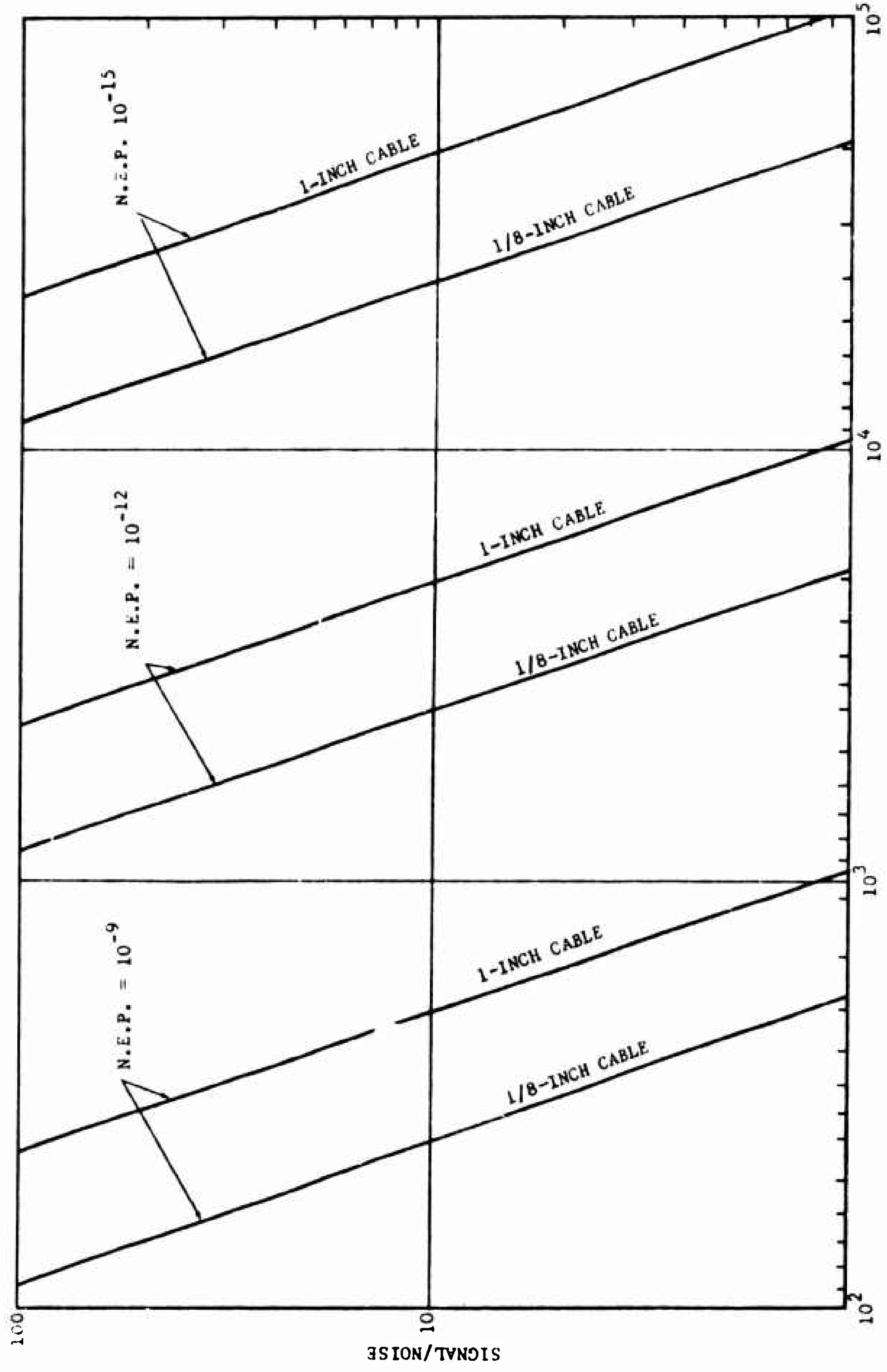


FIGURE [illegible]IRE DETECTION WITH OPTICAL RADAR

$$\frac{A_T}{A_B} \cdot P_T = \text{Power on target} = P_{OT} \tag{3}$$

where

A_T = Area of target

A_B = Area of beam at target

P_T = Power transmitted

$$A_B = \frac{\pi}{4} (R \cdot \theta)^2 = \frac{\pi}{4} \cdot R^2 \cdot \theta^2 \tag{4}$$

Therefore,

$$P_{OT} = \frac{P_T \cdot A_T \cdot 4}{\pi \cdot R^2 \cdot \theta^2} \tag{5}$$

$$P_{TT} = P_{OT} \cdot \rho \tag{6}$$

where

P_{OT} = Power on the target

ρ = Target reflectivity

P_{TT} = Power transmitted from target

$$P_{TT} = \frac{P_T \cdot A_T \cdot 4 \cdot \rho}{\pi \cdot R^2 \cdot \theta^2} \quad (\text{For } A_T < A_B) \tag{7}$$

For a point source radiating uniformly in all directions,

$$I_r = \frac{P}{4\pi} \tag{8a}$$

where

I_r = Radiant intensity

P = Power radiated

For a source radiating over a hemisphere,

$$I_r = \frac{P}{2\pi} \tag{8b}$$

P in equation (8b) is the power transmitted from target P_{TT}.

So

$$P_{TT} = I_r \cdot 2\pi$$

$$I_r = \frac{H \cdot R^2}{\mathrm{Cos}\ B} \quad \text{(From Ref. 9)} \tag{9}$$

where

H = Radiance flux per unit area

B = Angle of beam incidence on target

$$P_{TT} = \frac{2\pi \cdot H \cdot R^2}{\mathrm{Cos}\ B} \tag{10}$$

$$H = P_R / A_R \tag{11}$$

where

A_R = Receiving area

P_R = Power Received

$$P_{TT} = \frac{2\pi \cdot P_R \cdot R^2}{A_R \ \mathrm{Cos}\ B} \tag{12}$$

Equating 12 and 7,

$$\frac{2\pi \cdot P_R \cdot R^2}{A_R \ \mathrm{Cos}\ B} = \frac{P_T \cdot A_T \cdot 4 \cdot \rho}{\pi \cdot R^2 \cdot \theta^2}$$

Solving for P_R,

$$P_R = \frac{P_T \cdot A_T \cdot A_R \cdot \rho \cdot \mathrm{Cos}\ B \cdot 2}{\pi^2 \cdot R^4 \cdot \theta^2} \quad (\text{For } A_T < A_B) \tag{13}$$

Equation 13 is a general equation where the target area (A_T) is smaller than the area of beam at target (A_B). If A_T is equal to or larger than A_B, then

$$P_{OT} = P_T \tag{14}$$

Therefore, from equation 6 ,

$$P_{TT} = P_T \cdot \rho \tag{15}$$

Equating 15 with 12,

$$P_T \cdot \rho = \frac{2\pi \cdot P_R \cdot R^2}{A_R \cdot \text{Cos } B} \tag{16}$$

Solving 16 for P_R,

$$P_R = \frac{P_T \cdot \rho \cdot A_R \cdot \text{Cos } B}{2\pi \cdot R^2} \quad (\text{For } A_T \geqq A_B) \tag{17}$$

Equations 13 or 17 should be modified by the following attenuation and efficiency factors:

1. Atmospheric attenuation

2. Transmitter efficiency

3. Receiver efficiency

These factors are all less than one and should be multiplied by the numerator of the equation. The product of these three factors would have to be less than .13 before the 2,500-yard detection of the 1/8-inch cable, shown in Figure 13, could be reduced to the required 1,000-foot detection range. The parameters that were utilized to calculate the ranges shown in Figure 13 were as follows:

P_R = Power received

P_T = Power transmitted = 1 kw

ρ = Target reflectivity = .1

T_R = Receiver efficiency = .7

A_R = Receiving area = $\frac{\pi}{64}$ (3-inch optics)

θ = 3 milliradians

Efficiency of transmission through the atmosphere was considered to be 1.0 for these calculations.

Background radiation that appears as noise to the receiver is not considered in the calculation of the radar detection range. It is realized that the noise from the background may contribute a large signal

during landing when the radar has the earth as a background; however, during level flight the range to ground is greater than the range to obstacle, and it may be possible to gate out the majority of the background noise.

The detection range calculations have not considered any requirement for scanning to accomplish the required angular coverage of the obstacle-avoidance system. However, the sector to be scanned is small enough that the pulse rate of 300 PPS will furnish data at the rate required by the performance of the various Army aircraft. This pulse rate is well within the state of the art and does not require water cooling of the laser.

Figure 13 shows detection range in yards versus signal/noise for three receiver noise equivalent powers (NEP). These three curves were calculated by utilizing equation 13 and substituting NEP for power received. The other parameters used in the calculations are as listed in the text.

Passive Sensors

Passive sensors are those that make use of the natural radiation emitted by or reflected from objects within the sensor field of view. Passive sensors in the microwave, infrared, and visual ranges of the electromagnetic spectrum are of interest. In each case the sensor provides a "picture" of the scene that it views, but the characteristics of these "pictures" vary markedly from one case to another. For example, the resolution of a microwave radio-metric sensor is significantly poorer than the unaided eye, while that of a television sensor can be better than the unaided eye.

The chief military appeal of passive sensors is the fact that they are not detectable. A basic drawback of this class of sensors is that direct range information (such as given by a radar system) is not obtained for the various objects in the scene. Alternatively, one can conceive of passive sensors which obtain range information indirectly by stereoscopic or parrallax effects. However, these would involve highly sophisticated processing of the sensor images and are not practical for near-future systems.

Without range information, obstacle detection must be based on recognition of the object within the viewed scene. Since automatic obstacle detection is desired, the problem is placed in the realm of automatic pattern recognition, which at present is only in the exploratory research stage. In addition, the passive sensors investigated are hampered by variations in obstacle/background contrast, as noted in Table 23 in Appendix II.

In view of their severe limitations as obstacle detection devices, it is of interest to consider whether passive sensors may have some usefulness in providing situation displays once an obstacle has been detected.

In this role, passive sensors might supplement the capabilities of the unaided eye in bad weather (through microwave radiometry), at night (through infrared radiometry or low-light-level television), or in clear daylight (by providing improved resolution through a televesion sensor). The usefulness of a situation display in the obstacle-avoidance situation will depend primarily upon the field of view and the resolution. Earlier considerations indicate that an angular field of view 10 degrees by 10 degrees would be adequate. Similarly, the ultimate goal in resolution would be ¼ inch at a distance of 2,000 feet. By comparison, all-weather microwave radiometry could typically provide a resolution of 30 feet at a range of 2,000 feet, being limited by antenna size and wavelength. This would give only a very coarse picture, useful for major terrain features and large structures. Infrared and conventional television sensors would give much improved resolution, typically 2 feet at 2,000 feet; this is comparable to naked-eye resolution. To approach the potential for discerning distant wires, it is necessary to consider very-high-resolution TV techniques now under development. These will provide a capability for an 8,000-line picture in the near future, thus giving a theoretical resolution of ½ inch at 2,000 feet with a 10-degree by 10-degree field of view. The practical difficulty encountered here, however, is one of sensor stabilization, since this ultimate resolution will be "washed out" by very slight motions of the sensor optic axis. In a high-vibration environment, resolution improvements much beyond naked-eye capability will require costly stabilization techniques. In any event, the use of an auxiliary pictorial display appears to be incompatible with the demands already imposed upon the pilot by low-level operations under hazardous conditions.

The one application of passive sensing to the obstacle-avoidance problem which appears worthy of further investigation is that of an auxiliary sensor for alignment of an active (radar) obstacle detector with the flight vector. The basic approach would be to make use of flight-direction information inherent in the relative motion of various objects within the scene viewed by the passive sensor. This is discussed in more detail in the section on sensor alignment by passive systems.

SENSOR ALIGNMENT

The need for sensor alignment is emphasized by comparing the relatively low flight speeds of Army aircraft with probable crosswinds. For example, a crab angle of 30 degrees is required to fly at 60 knots in a 30-knot crosswind. Therefore, it is necessary to align the sensor with the flight path so that its field of view can be kept to a minimum. This permits maximum sensor resolution using minimum power. Angle of attack of the aircraft will vary between 5 degrees and 20 degrees, indicating a need for sensor alignment vertically as well as horizontally.

In the case of helicopters, the requirement for pointing the sensor becomes more complicated than for a fixed-wing aircraft because of the helicopter's capability to fly in almost any direction or to hover. A method of sensor stabilization is required for the sensor to observe

obstacles that are along or near the flight vector of the aircraft and thus to avoid collision with them.

Slaving of sensor line of sight to aircraft velocity vector can be accomplished by using signals of pitch, roll, and azimuth from a stable platform along with indications of angle of attack and drift angle from various airflow type sensors and some type of ground velocity sensor. To facilitate use of these signals, some form of gimbal drive system must be available to position the sensor.

Various stable platforms (gyrocompass or inertial navigation systems) are currently available and capable of providing the outputs of pitch, roll, and azimuth.

A typical example of one of the better gyrocompass systems is the SYP-820, described in Reference 10, with an in-flight verticality of 1 degree R.M.S. and total system weight below 30 pounds. Total volume of the system is approximately .44 cubic foot and power required is 100 volt-amperes. This system is more than adequate to supply the required inputs for sensor stabilization, and suitable angle-of-attack sensors are currently available.

A doppler radar navigation sensor can, by calculating the three vector components of aircraft velocity, obtain the resultant velocity vector of the aircraft with respect to an aircraft coordinate system. This information can be utilized by a computer to direct the obstacle-avoidance sensor to point along the velocity vector of the aircraft. This system will not require inputs from a stable platform unless pitch and roll stabilization of the doppler antenna is required to insure the beams always striking the ground under the aircraft, to insure an adequate return to the receiver.

Several doppler radar navigation sensors are presently available that have the capabilities required for this type of utilization. Laboratory For Electronics and Canadian Marconi both are developing or have developed systems capable of performing this function. A typical one is the 600 series of L.F.E. described in Reference 11. It is expected that growth potential (5 years) will produce a system weighing 18 pounds, being .7 cubic foot in volume, operating on only 90 watts of power, and approaching a predicted Mean Time Between Failures (MTBF) of 10,000 hours. The Canadian Marconi system is described in Reference 13.

The inertial navigation system also has the capability of determining the velocity vector of the aircraft. Several inertial systems are available or can be made available in the near future. One of the systems to fill this role is the low-cost inertial system (LCI) of General Precision, Inc., in Reference 12. The system will weigh 20 pounds and will have a volume of 506 cubic inches. Power required is 55 watts.

It is possible for the pilot to manually point an obstacle-avoidance sensor along the estimated flight vector. However, the errors which can

accumulate during busy flight periods tend to increase the detection-range and field-of-view requirements of the sensor to a point well beyond the current state of the art.

The changing scene viewed by a passenger in a moving vehicle provides information regarding the direction of motion of the vehicle. It is therefore of interest to consider the ways in which a passive sensor might make use of this information. First, however, a quantitative description of the direction-of-motion cues given by the apparent angular motions of objects is needed. This can be provided most concisely by a vector analysis of the situation.

Let $\bar{V}$ be the velocity vector of the aircraft, and let $\bar{R}$ be the position vector (at a given instant of time) of an arbitrary object with respect to the aircraft. Then the time-derivative of this position vector, for an object in the forward hemisphere, is the negative of the velocity vector:

$$-\bar{V} = \frac{d}{dt} (\bar{R}) \tag{18}$$

To treat apparent angular motion separately, it is convenient to express the vectors as products of a magnitude (R or V) and a unit vector ($\hat{r}$ or $\hat{v}$) in the appropriate direction. Then

$$-\hat{v} V = \frac{d}{dt} (\hat{r} R) = R \frac{d}{dt} (\hat{r}) + \hat{r} \frac{d}{dt} R \tag{19}$$

The quantity of interest is the $\frac{d}{dt}(\hat{r})$, the rate of change of direction to the object:

$$\frac{d}{dt} (\hat{r}) = -\frac{\hat{r}}{R} \frac{d}{dt}(R) - \frac{V}{R}\hat{v} \tag{20}$$

Since $-\frac{d}{dt}$ (R) is equal to $(\hat{v} \cdot \hat{r})$ V, the component of $\bar{V}$ along $\bar{R}$, we have

$$\frac{d}{dt} (\hat{r}) = \frac{V}{R}\left[\hat{r} (\hat{v} \cdot \hat{r}) - \hat{v}\right] \tag{21}$$

This expression gives the direction and rate (in radians per second) of apparent angular motion of the object as viewed from the aircraft. The angular rate is a function of aircraft speed, range to the object, and direction of the object with respect to the velocity vector. The direction of angular motion is in the plane of $\bar{V}$ and $\bar{R}$. This demonstrates, as expected, that when the field of view is projected onto a plane, all objects appear to move radially outward from that point which represents the direction of motion. For that particular point, $\hat{v} \cdot \hat{r}$ is unity (since the unit vectors are parallel) and there is no angular motion, i.e.,

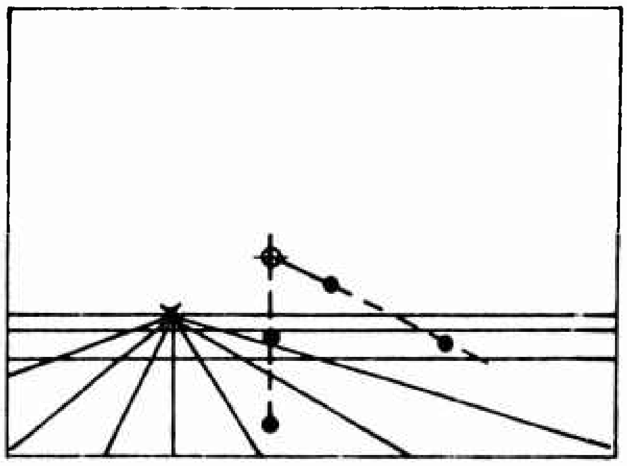
$$\frac{d}{dt}(\hat{r}) = 0 \qquad (22)$$

To illustrate the large variation in angular rates encountered, consider an aircraft in level flight at 90 knots (150 feet/second) at an altitude of 100 feet. Objects passing directly beneath the aircraft ($\hat{v} \cdot \hat{r} = 0$) have an apparent angular rate of 1.5 radians per second. On the other hand, objects on level terrain one-half nautical mile ahead of the aircraft ($\hat{v} \cdot \hat{r} = 1 - \frac{1}{1800}$) have an apparent angular rate of only .03 milliradian per second. This shows the difficulty inherent in sensing apparent motion of objects close to the projected flight path.

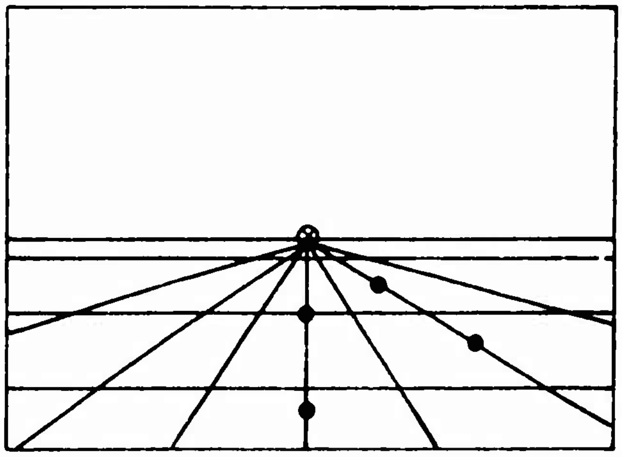
A passive alignment device would operate by automatically identifying the point corresponding to zero angular motion. One approach would be frame-to-frame comparisons, using signal subtraction to erase all objects with apparent motion, leaving only the object along the flight direction. Difficulty is encountered when that portion of the field of view in the vicinity of the flight direction contains no discernible objects.

An alternative approach would make better use of the information provided by objects which do have apparent angular motion. As noted earlier, the angular rates of various objects are unpredictable (especially in rugged terrain, for example) because of the range dependence, but the directions of motion are all radially outward from the direction of flight. Hence, one might use several pairs of detectors in the sensor image plane, the pairs lying in various planes containing the sensor optical axis per Figure 14. When the optic axis is aligned with the velocity vector, objects which pass across one detector of a pair will a short time later pass across the other member of the pair farther from the optic axis. A continuous comparison, by signal cross-correlation of the outputs, of a given detector pair could then establish whether the sensor is properly aligned. The arrangement is illustrated for the simple case of level flight over flat terrain. The accuracy, response speed, and assurance of operation for various scene content would improve as the number of detector pairs is increased; however, the complexity of the signal processing circuitry would also be increased.

Some simplification can be achieved by reducing the capability of the passive sensor to that of drift angle measurement only. In that case, the sensor's field of view would be centered below the aircraft and the pairs of detectors would be along parallel fore-aft lines. This sensor would be an automatic version of the usual manual drift sight. Its usefulness stems from the fact that drift angle, caused by steady-state horizontal wind, is the largest unknown in the velocity-alignment problem. The other unknown, angle of attack, can be measured with sufficient accuracy by an air data sensor, since steady-state vertical winds are rare in the low-altitude situations of interest here.



a) Sensor Misaligned



b) Sensor Aligned

x = direction of flight

o = sensor optic axis

● = detector locations in field of view

FIGURE 14. PASSIVE SENSOR OPTICAL ALIGNMENT

In summary, the study of passive optical alignment techniques has not been pursued to the extent that a definitive statement regarding feasibility can be made. However, the concept does appear worthy of further investigation.

DATA PRESENTATION TO PILOT

Presentation of an obstacle warning to the pilot can be auditory, visual, or, perhaps, both. The warning should be clear and unambiguous to allow time for an avoidance maneuver.

Visual

During most phases of flight, an illuminated warning light is readily discernible by a trained pilot. However, some flight phases require that the pilot's attention be concentrated outside the cockpit. It is during these times within the mission profile that a pilot can be unaware that an unsafe warning light is on.

Another consideration concerns the time required to interpret the meaning of the light. When the light comes on, the pilot first has to perceive it. Then, he must decide the action to take as well as initiate this action. A steady or flashing light activated by a sensor does not give the range information necessary for optimal maneuvers. A "barber pole" type indication could be instrumented to imply a range value. CRT and/or pictorial presentations require continuous monitoring on the part of the pilot and would not be suitable displays for low-altitude VFR flying when the external viewing requirements are so high.

Reaction time to visual warning lights during stressful flight operations increases and is described graphically in Figure 15. Consideration of the low experience level of the pilots involved in the obstacle strikes analyzed indicates the great value of a simplified warning presentation. The trainee with under 100 hours of flight time is in the process of developing patterns of response to complete stimulus situations, but coordination and timing are still uncertain and reaction times are long. Rather than being controlled in large part by automated response, the trainee's performance is complicated and confused by many minor decisions. Thus, he is in the process of learning precision and coordination of movements, serialization of responses, and the perceiving of larger blocks of information per unit of time. At this stage of learning, a visual indicator requiring perception and interpretation may create a task marked by considerable subjective confusion, and may interfere with the required response. This lack of temporal integration of the processes of perception, mediation, and response reaction will be improved with training experience. However, obstacle strikes remain a real possibility until the trainee has reached an effective level of information processing, decision making, and response initiation.

Another problem especially acute in helicopter operation is vibration,

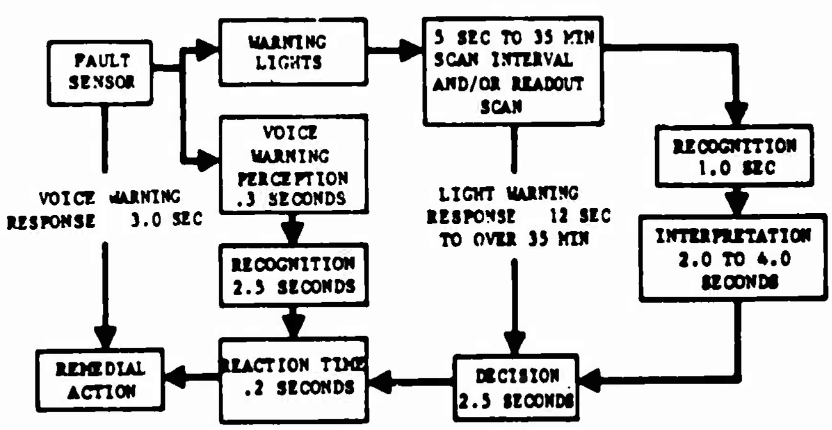
which can excite the instrument panel, the pilot's body, and his head at different resonant frequencies, with serious impairment of visual acuity and perception. In contrast, the aural sense, as utilized by a voice warning system, is relatively unaffected. In fact, with a voice warning system, there is no appreciable loss of effectiveness with vibration, buffeting, eye orientation, load factor, light glare and/or modulation, noise or other environmental phenomena. Further, there is no learning period required to interpret a voice warning. Minimal use of voice warnings results in word associations, which further reduce response time.

Due to reaction times associated with visual warning systems, the level of experience of the trainee, and the perceptual and evaluative requirements of a light or barber pole display, it appears that an auditory system could facilitate a reduction of obstacle strikes. If, however, a visual system were required, it is recommended that the barber pole display be placed in the crew station within the range of the pilot's peripheral vision.

Auditory

Several considerations are important to the selection of an auditory warning system. The temporal integration problems of the trainee associated with visual warning systems also apply to the use of a bell or buzzer. Under the stress of the training situation, the auditory signal, although reducing reaction time in general, may go unnoticed or unperceived by the trainee. It may also be confused with landing gear/stall warning systems and create a subjectively confused situation during interpretation and selection of response. In addition, these systems do not include ranging information unless pitch or loudness are varied, in which case additional interpretative processes would be required by the pilot.

The most efficient warning system would be the recorded voice warning. A comparison of pilot reaction time and sequence with visual and voice warning systems is presented below.



REFERENCE: NORTHROP/NORTRONICS REPORT NORT 64-250

FIGURE 15. VOICE WARNING RESPONSE

Additional incidence on recorded voice warning systems was obtained on F-100F studies. Response times to visual indicators alone averaged 44.05 seconds. Response times to identical situations presented verbally averaged 2.93 seconds. Of particular interest was the difference between these two systems for various mission segments as shown in Table 13.

TABLE 13

COMPARISON OF RESPONSE TIMES TO VISUAL AND VERBAL WARNING SIGNALS DURING VARIOUS FLIGHT PHASES (ALL RESPONSE TIME FIGURES ARE IN SECONDS)*

FLIGHT PHASE	AVG & RANGE OF VISUAL RESPONSE TIMES	AVG & RANGE OF AID RESPONSE TIMES
Climb Out	Avg. 23.82 R. 1.8 - 278.8	Avg. 2.92 R. 2.8 - 5.8
Cruise	Avg. 7.13 R. 1.9 - 57.4	Avg. 2.78 R. 1.8 - 4.6
Penetration	Avg. 67.19 R. 1.8 - 762.4	Avg. 2.89 R. 2.1 - 4.9
Low Level	Avg. 128.27 R. 1.8 - 622.1	Avg. 3.03 R. 1.8 - 6.6

*TAC-TR-62-20 Reference 4

It is seen that the average response time is quite sensitive to the pilot's outside workload.

In the training environment, it appears necessary to present the trainee with information that he will readily perceive, understand, and react upon. A voice warning system not only could alert the trainee to potential dangers but could spell out action required to avert a mishap. In general, the system would not be affected by:

1. Trainee preoccupation with other tasks

2. Cockpit lighting and glare

3. Vibration and acceleration effects

4. Concentration on "out of window flying"

A voice warning system could minimize the pilot reaction time, and corrective action could be taken concurrently with operational task learning. In the case of helicopters, the environment presents vibration, modulating light, high noise levels, and conditions which materially in-

crease fatigue and degrade visual perception. It has been demonstrated that pilots react to auditory signals even after they have lost their ability to respond to visual stimuli.

The voice warning system would also alleviate the phenomenon of fascination, particularly in training, which results from overconcentration (fixation) on some instruments or tasks and produces a state of narrowed attention with loss of voluntary control over response.

In conclusion, the voice warning system has the following advantages:

1. Relieves the pilot and/or crew of the constant monitoring of a cautionary warning-light or visual presentation.

2. Increases the probability of signal detection by using an additional sense modality.

3. Insures crew perception of warning; signal not affected by cockpit vibration or by glare of high-altitude sunlight or modulating light in rotary-wing applications.

4. Improves combat effectiveness; faster crew reaction to hazards gives greater confidence in ability to operate at low altitudes when following unfamiliar terrain.

EVALUATION OF PROPOSED CONCEPTS

Landing Aid

Evaluation of the different system concepts is based on an estimate of the number of predicted obstacle strikes which each would prevent, along with estimates of size, weight, power consumption, and maintenance requirements. The statistics show that 32 percent of the impacts occurred during the landing phase. Therefore, the upper limit of the value of a landing aid system, if it were 100-percent effective, would be to eliminate approximately one-third of the total obstacle strikes. A limitation on the effectiveness of the landing aid lies in the use of landing areas which are not equipped with the glide slope devices. Rotary-wing aircraft particularly are expected to operate from fields which are devoid of any landing aids much of the time. If half of the aircraft operation is into these primitive areas, then landing aids installed at the heavily used Army airfields could eliminate one-sixth of the low-altitude obstacle strikes.

Trained Observer

The evaluation of a trained observer as an obstacle detection system is based on the advantage offered by dual search.

The statistics on low-altitude obstacle impacts show that the pilot causes are largely:

1. Pilot failed to see the obstacle.

2. Pilot misjudged distance, altitude, or position.

The impacts are divided between these two cause factors as shown below:

PERCENTAGE

	Failed To See	Misjudged
Of Tree Strikes	26	53
Of Wire Strikes	71	33
Of Total Strikes	39	47

Since 40 percent of the obstacle strikes are attributed to the pilot's failure to detect them, it follows that in 60 percent of the collisions, he had detected the obstacles but collided with them for some other reason. The pilot also detected and avoided some unknown number of obstacles.

The probability that a pilot detects an obstacle can be expressed by:

$$P = \frac{x + y}{x + y + z} \qquad (23)$$

where x = number of obstacles pilot sees and avoids

y = number of obstacles pilot sees but does not avoid

z = number of obstacles pilot fails to see

From the data, $y = .60\ (y + z)$;

therefore,

$$P = \frac{x + .60\ (y + z)}{x + y + z} = \frac{w + .60}{w + 1.0} \qquad (24)$$

where $w = \dfrac{x}{y + z}$

It can be seen from this equation that the probability of the pilot's detecting an obstacle is greater than .60 according to the number of obstacles that were detected and avoided. If it is assumed that both pilot

and observer have equal detection probability of .60, then from Figure 9, the combined probability of detection is .84. Therefore, by the use of a trained observer to assist the pilot in all low-altitude operations, the obstacle strikes should be reduced by at least 24 percent.

As seen on the above tabulation, pilot errors in judgment account for 47 percent of the obstacle strikes. It is expected that the observer would be trained to aid the pilot in the judgment of distance, or position, with a corresponding reduction of such impacts. However, a quantitative evaluation of this capability is not possible with the data available.

Another advantage of the trained observer concept lies in its ease of implementation. No aircraft modifications are required.

Radar Concept

An active radar obstacle-avoidance system is a feasible method of detecting obstacles in low-altitude flight. The passive sensors require target/background contrast or heat differentials to obtain detection. As noted in the situations in Table 24 of Appendix II in this report, the contrast is often insufficient for detection.

The main drawback to the active sensors is their requirement for components in order to become a complete obstacle-avoidance system. Components required are a velocity sensor, a computer, a method of stabilization, and some type of a presentation (either visual or aural).

The optical radar has the capability of detecting 1/8-inch wire at a range far greater than that required by the fastest aircraft programmed for the Army inventory. The weight of the laser is estimated as 70 pounds in 1-cubic-foot volume, and the power required is approximately 3 kilowatts.

As shown in Figure 11, the detection capability of the millimeter radar is marginal against the 1/8-inch wire with the 1-foot-diameter dish.

Both the laser and the millimeter radar require stabilization and continuous alignment. The alignment method which appears to be most practical is the inertial platform with accelerometers, and integrators to locate the aircraft velocity vector. The inertial platform system is estimated to weigh 20 pounds in .3 cubic foot and to use 55 watts of power.

The presentation of the obstacle warning to the pilot must be unmistakably clear and concise. The pilot must be made aware of the existence of an obstacle in as short a time as possible, without ambiguity or confusion. The presentation methods studied are: a flashing panel light which would fall within the pilot's peripheral vision, a horn or buzzer, a voice recording, a pictorial display on a cathode ray tube, and a digital data display on the instrument panel. Instrument panel displays are

considered incompatible with low-altitude flight because of the demand for the pilot's attention outside the cockpit, on the terrain ahead, along the flight path. The time required to divert the pilot's attention from the flight path to the instrument may be prohibitive. An auditory signal does not require the diversion of visual attention even momentarily and is therefore considered superior for this application.

VISUAL VERSUS RADAR DETECTION

In comparing visual observation with radar or other sensor systems, the conclusion reached is that they must augment each other. The capabilities, limitations and other factors concerning sensor equipment are discussed elsewhere in this report. From the examination of visual capabilities, it appears that first consideration must be given this area, the trained observer concept, as a means of reducing in-flight obstacle impacts.

Some limitations in respect to visual detection where electronic sensing would augment the eye may be considered from the following. The eye, when searching systematically, tends to look in one field in a specific direction for a short period of time (about a second). In this time interval several fixations occur, and then the eye skips to a new line of sight. The direction frequently differs from the previous line of sight by as much as 10 degrees. The eye can resolve distant objects, under normal conditions, only within an area of about 1 degree. The distant coverage pattern for visual search tends to be ragged. Due to the broad lobe of peripheral vision at shorter ranges, larger objects off the direct line of sight are readily detected, but there is a considerable probability that small objects at long range will be passed over.

Radar scans continuously and does not experience the gaps in coverage that the eye does. Its rate of scanning is considerably higher than that of the eye, and of course radar is uninhibited by obscurations to visibility. These things taken together support the use of detection devices to augment normal visual means.

VI. AIRCRAFT DESIGN IMPLICATIONS

The obstacle-detection systems discussed previously in this report are: the glide-slope landing aids, the copilot observer, and the electronic sensors. The optical landing aids do not require any equipment to be installed in the aircraft, but the Honeywell terminal approach system requires an airborne radio receiver and a cockpit instrument display. The radio system is operable over a much greater range than either the "mirror" system or the "rainbow" landing aid, by approximately a factor of five.

The use of a trained observer for obstacle detection during low-altitude flight may require little or no aircraft modification. It is expected that the copilot position would normally accommodate such an observer and meet all the requirements for visibility. The copilot's cockpit tasks would not normally conflict with low-altitude observation and obstacle-warning activity.

The use of an electronic warning system for low-altitude hazards presents problems of installation in current and programmed future Army aircraft. The most practical mounting is an external pod mounting on the bottom of the fuselage. A radar antenna requires swivel mounting to meet scanning requirements, and the external pod offers the simplest solution, with the aircraft power supply transmitted through a small pylon. The radar system components can all be packed into a single pod to make the unit interchangeable for different aircraft models.

Obstacle-avoidance system installation would probably be a very simple matter if the aircraft is designed for IHAAS or ILLAAS. Since navigation systems and terrain-following systems perform many of the functions required of an obstacle-avoidance system, integration of the obstacle-avoidance system with the other avionics units should present little in the way of installation problems.

To summarize, aircraft design changes are required only for the radio type glide slope system and for the radar obstacle detection system.

The procedural analysis, as noted, disclosed no procedural problems which might be corrected by aircraft modification.

BIBLIOGRAPHY

1. Headquarters U. S. Army Aviation Materiel Command, Army Aircraft Availability and Downtime Statistical Digest.

2. Birmingham, Harry P., Rainbow Optical Landing Aid Paper presented at Aviation Contractors Safety Representatives Conference, Norfolk, Virginia, 6 April 1965.

3. Honeywell Inc., Proposal No. 4-09-21 Simplified Tactical Approach Terminal Equipment.

4. Tactical Air Command, Operational Test and Evaluation, Verbal Warning System, TAC-TR-62-20, 3 November 1963.

5. Westinghouse Aviation Handbook, HB-6012-A.

6. Oshiro, F. K., A Source Distribution Technique for the Solution of General Electromagnetic Scattering Problems, Northrop Corporation Report NOR 65-51, 25 February 1965.

7. Crispin, Jr., J. W., and Maffet, A. L., Radar Cross-Section Estimation for Simple Shapes, I EEE Proceedings, Vol. 53, No. 8, August 1965.

8. Skolnik, M. T., Introduction to Radar Systems, McGraw-Hill, 1962.

9. General Electric Corporation, Optical Engineering Handbook.

10. Sperry Gyroscope Company, Division of Sperry Rand Corporation, Great Neck, New York, Sharp Attitude and Heading Reference System, Publication No. CA-60-0023A.

11. G. P. L. Division, General Precision Aerospace, Pleasantville, New York, Doppler Velocity - Altimeter System for Helicopters, VTOL and Fixed Wing Aircraft, 17 March 1964.

12. Systems Division, General Precision, Inc., Aerospace Group, Wayne, New Jersey, LCI General Precision's Low Cost Inertial Syetem.

13. Canadian Marconi Company, Montreal, Canada, Technical Proposal P-682 For a Lightweight Airborne Doppler Navigator, 14 September 1965.

14. Northrop Corporation - Nortronics Division, NORVIPS, Voice Warning System Applications in U. S. Army Aircraft, NORT 64-25.

15. Department of Defense Appropriations, House of Representatives, Part 2 Operations and Maintenance for Fiscal Years 1963, 1964, 1965, and 1966.

APPENDIX I

ACCIDENT STATISTICAL ANALYSIS

The statistics surveyed in the analysis covered all the known Army aviation tree strikes and wire strikes extending approximately from the beginning of FY 1965. No data were provided on the character of the total pilot population or on the hourly, weekly, and monthly distribution of flight hours for different models of aircraft. Accident statistics by themselves lead only to intuitive conclusions and require comparison with other types of data for complete evaluation.

CARGO AIRCRAFT

Figure 16 shows the rate of occurrence of obstacle strikes per 100,000 flight hours for cargo type aircraft. The CH-21 and CH-34 rotary-wing aircraft show a significantly higher rate than the CV-2A/B fixed-wing aircraft. It is seen that the later-design cargo helicopters, CH-37 and CH-47, have encountered no tree strikes or wire strikes in the flight hours shown.

UTILITY AIRCRAFT

Figure 17 shows the rate of obstacle strikes for utility type aircraft. The rotary-wing aircraft, UH-19 and UH-1, have higher rates than the fixed-wing aircraft, U-1A and U-6A. However, the UH-1 has less than half the rate of the UH-19. The UH-19 and the U-6A show a slight downward trend with experience, while the UH-1 is stable and the U-1A rises. These rates appear to reflect the more hazardous operations associated with low-flying helicopters.

OBSERVATION AIRCRAFT

Figure 18 illustrates the rate of obstacle strikes suffered by observation type aircraft. The OH-13 has approximately three times the rate of the other aircraft, both fixed-wing and rotary-wing.

TREE AND WIRE STRIKES PER MODEL AIRCRAFT

Figures 19 through 24 show the separate rates of tree strikes and wire strikes for the rotary-wing aircraft being studied. The tree strikes invariably occur at a higher rate than the wire strikes, and the UH-19 appears to have the highest tree strike rate, while the OH-13 has the highest wire strike rate. Of the rotary-wing aircraft, the UH-1 appears to have the lowest wire strike rate and the OH-23 has the lowest tree strike rate.

From Figures 25 through 29, it can be seen that the OV-1 has the highest rates of both tree strikes and wire strikes of the fixed-wing aircraft. The manner in which the aircraft missions are flown probably is the largest single contributing factor. The rates are summarized in Table 7.

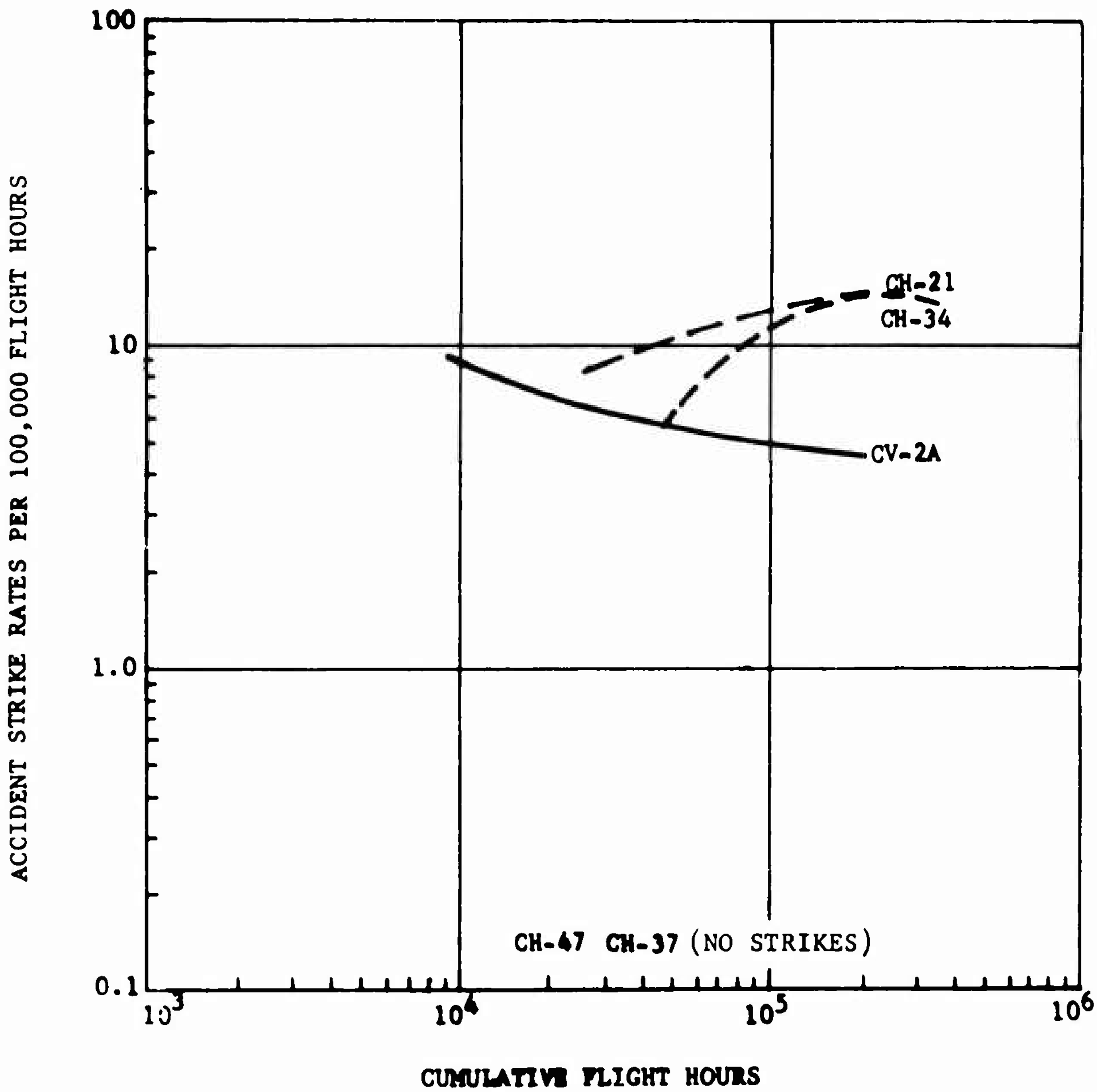


FIGURE 16 CARGO AIRCRAFT OBSTACLE IMPACT RATES

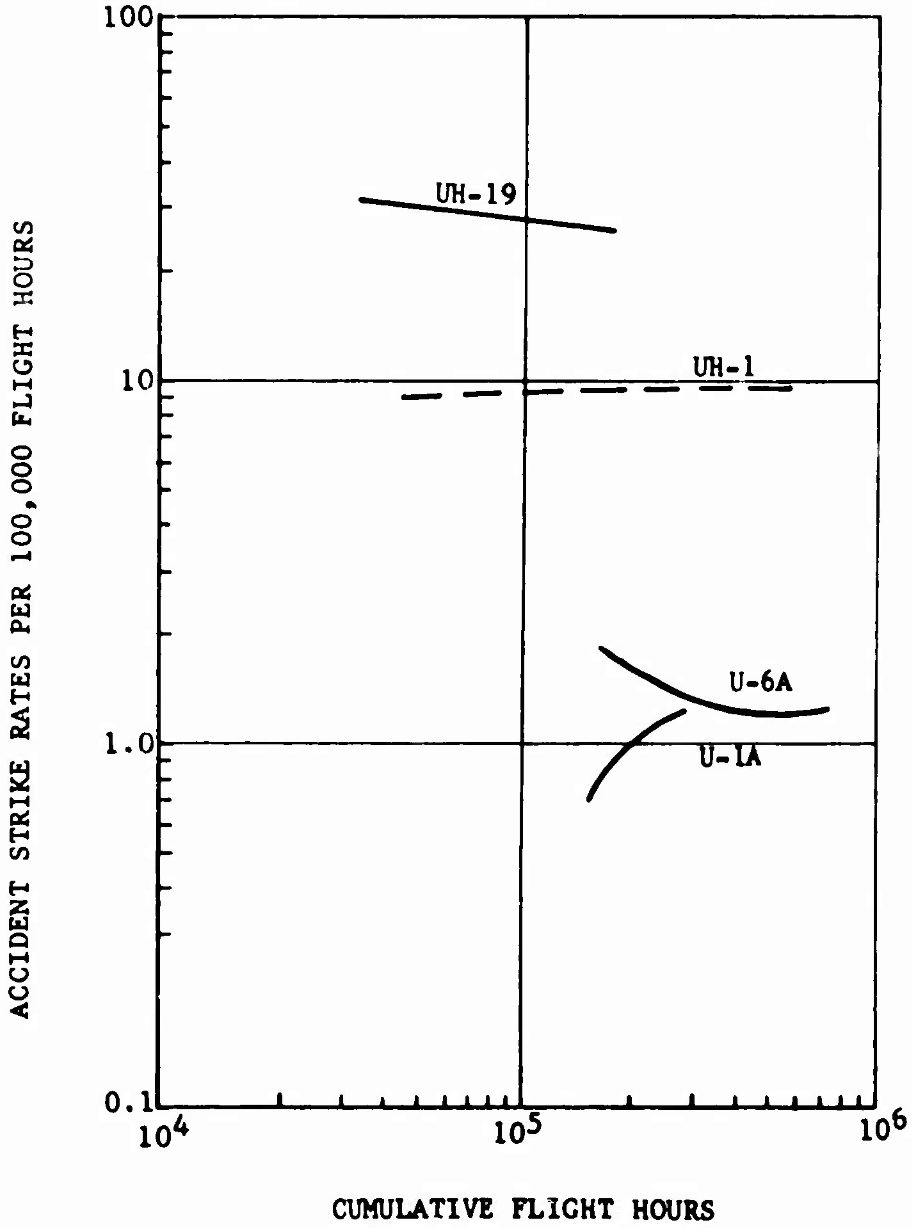


FIGURE 17. UTILITY AIRCRAFT OBSTACLE IMPACT RATES

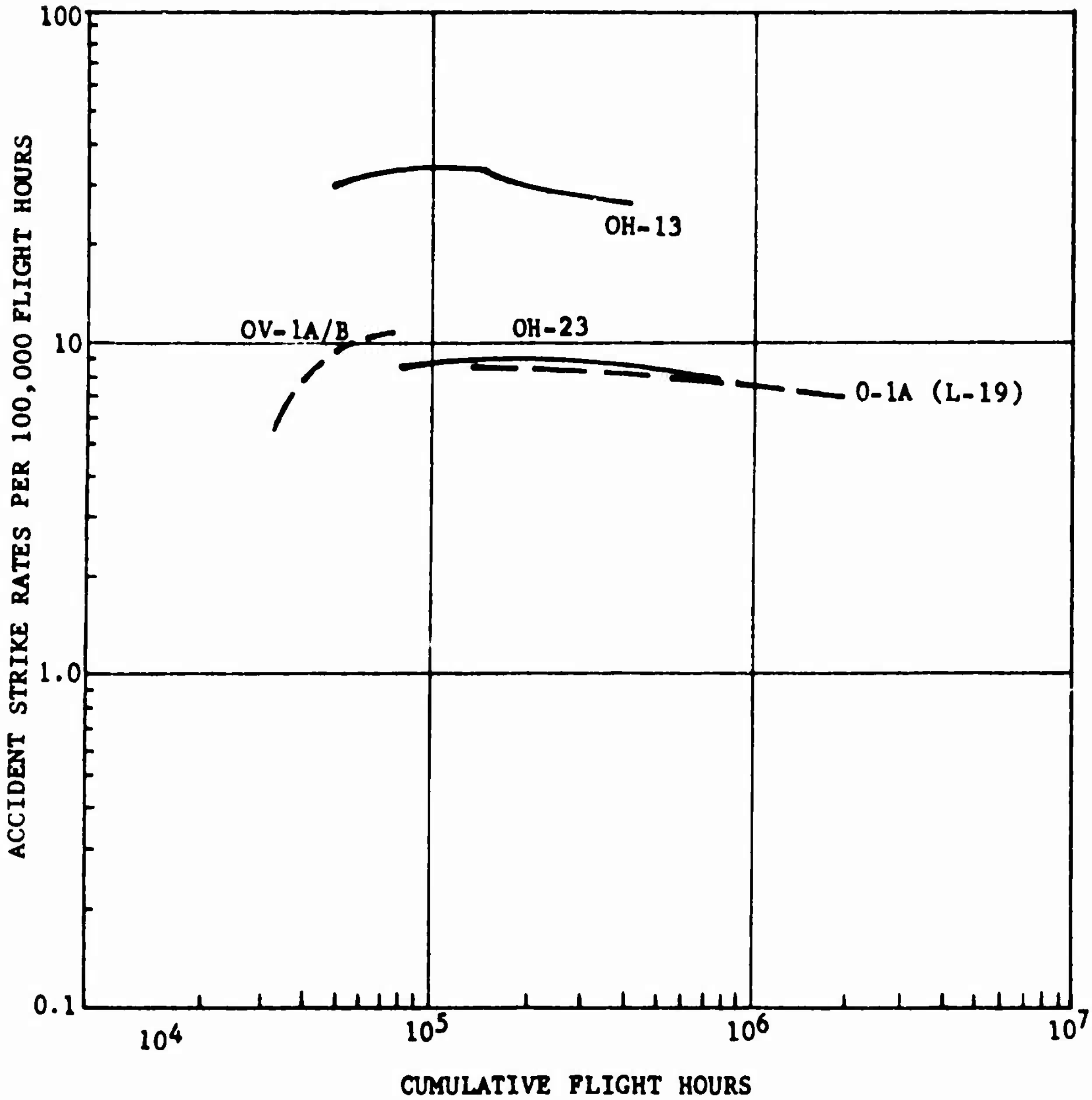


FIGURE 18. OBSERVATION AIRCRAFT OBSTACLE IMPACT RATES

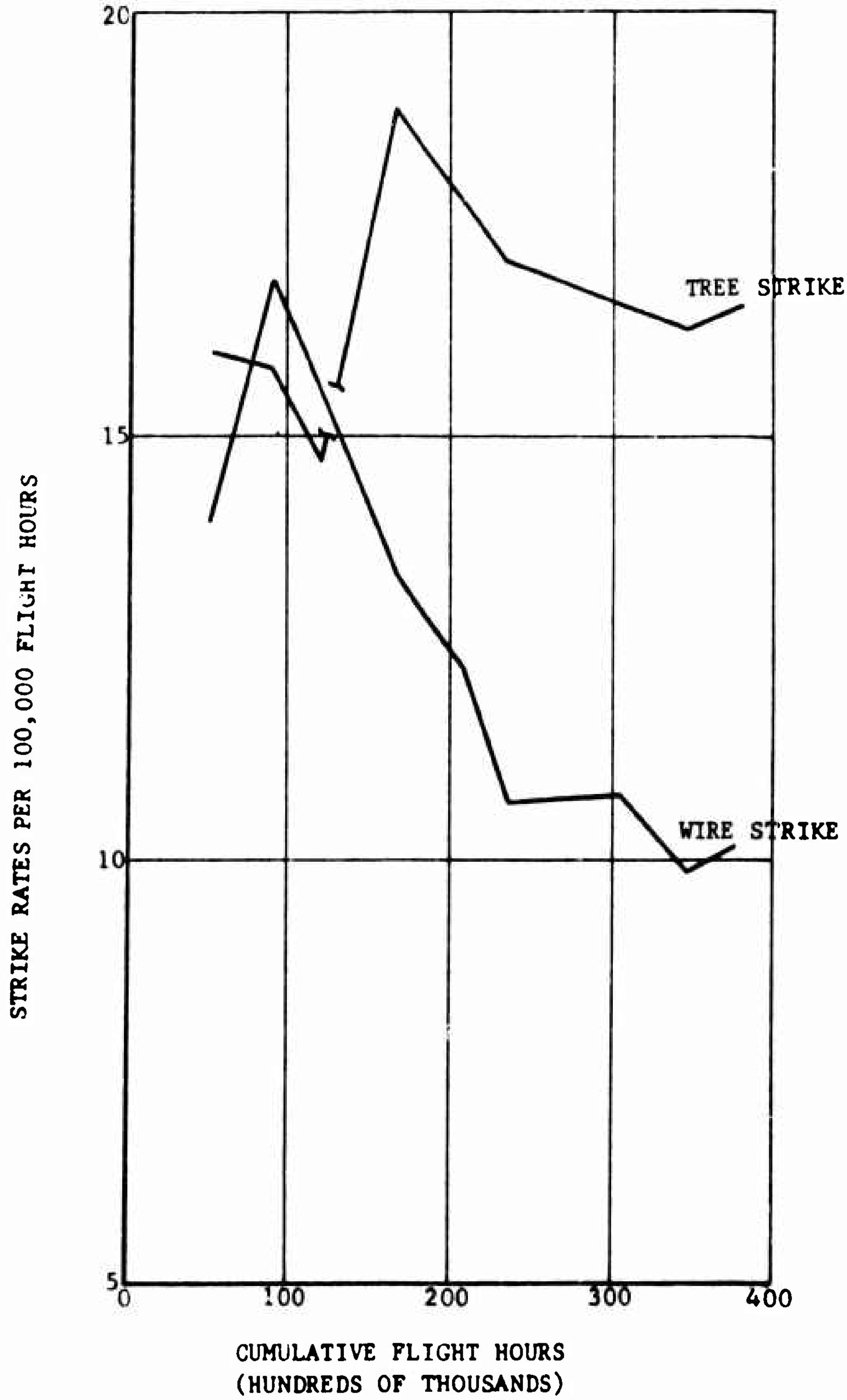


FIGURE 19. OH-13 SIOUX OBSTACLE IMPACT RATES

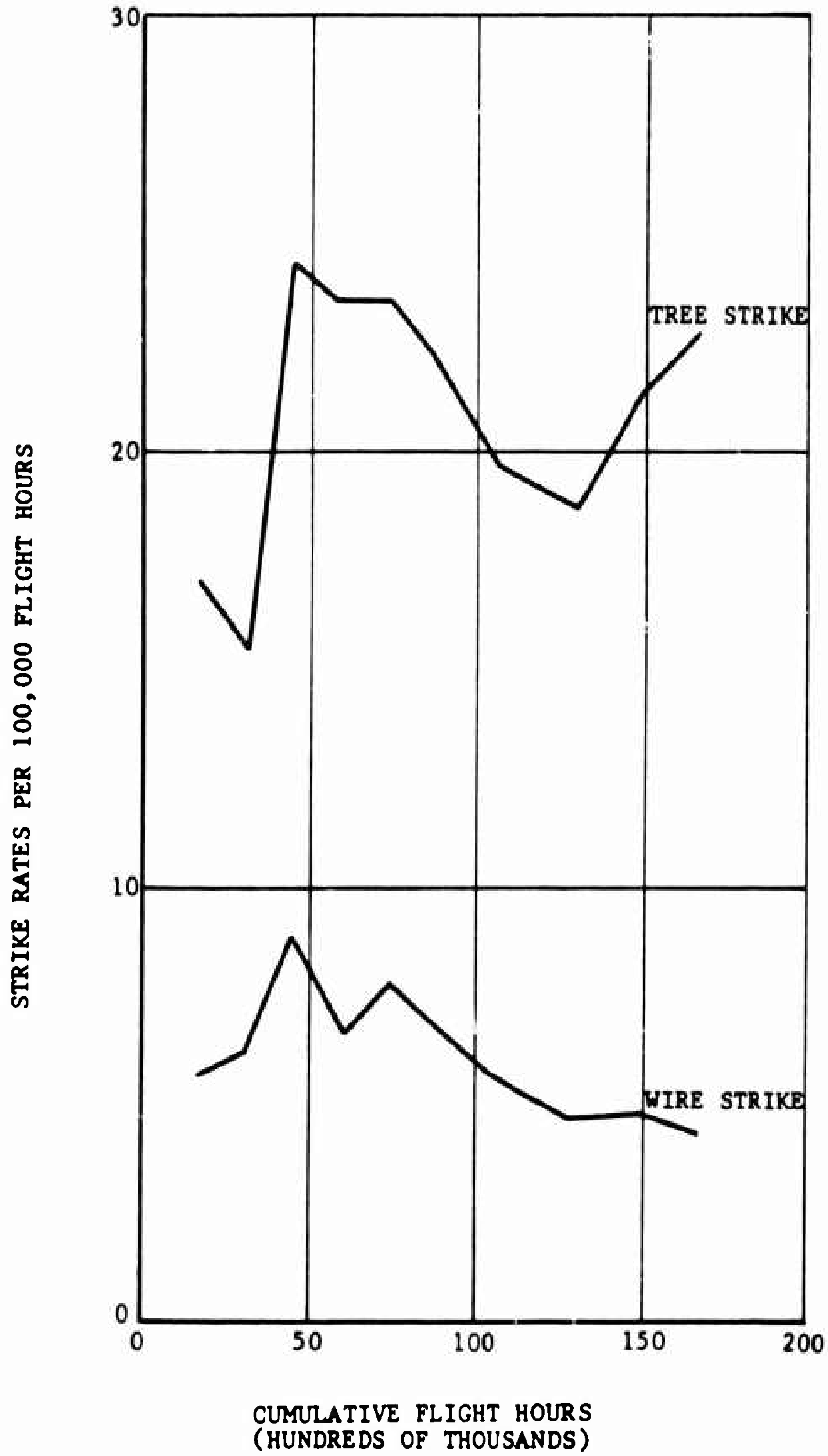


FIGURE 20. UH-19 CHICKASAW OBSTACLE IMPACT RATES

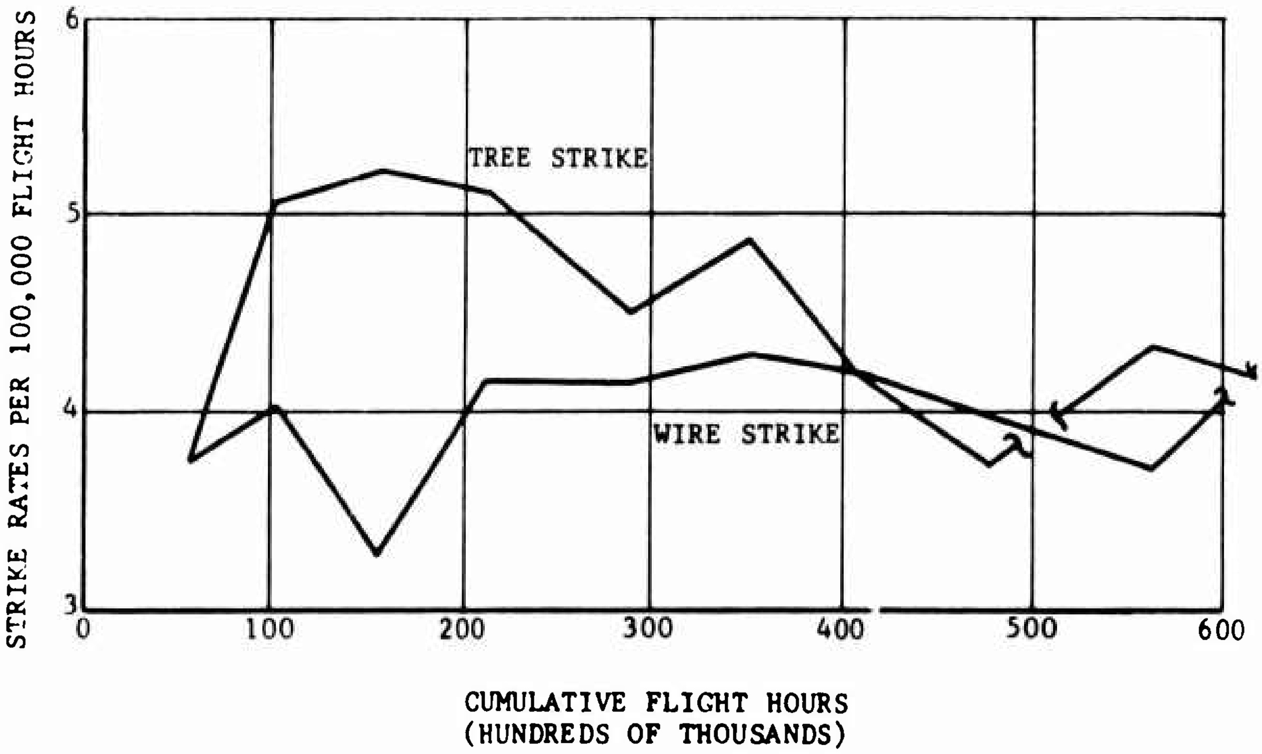


FIGURE 21, OH-23 RAVEN OBSTACLE IMPACT RATES

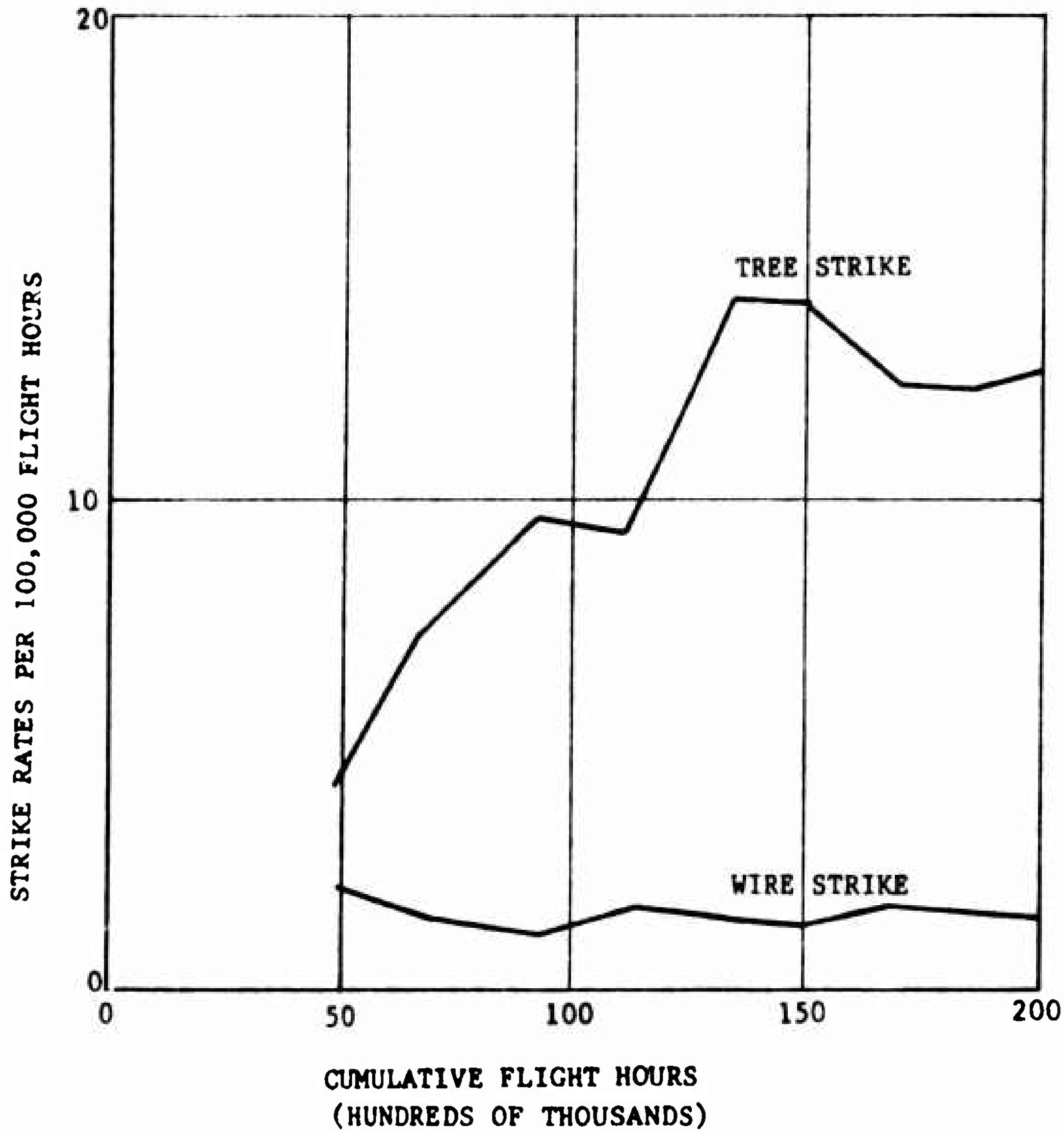


FIGURE 22. CH-34 CHOCTAW OBSTACLE IMPACT RATES

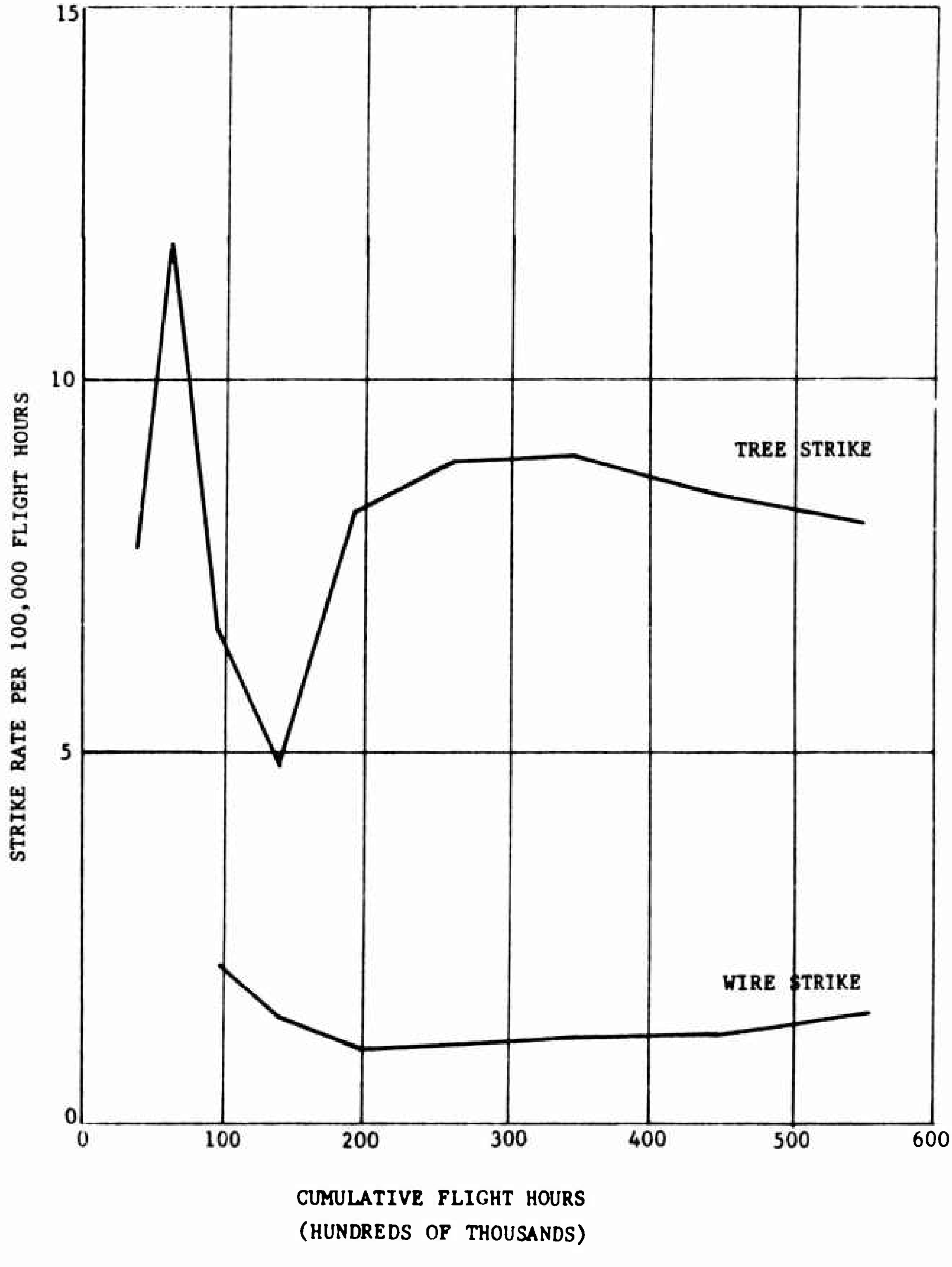


FIGURE 23. UH-1 IROQUOIS OBSTACLE IMPACT RATES

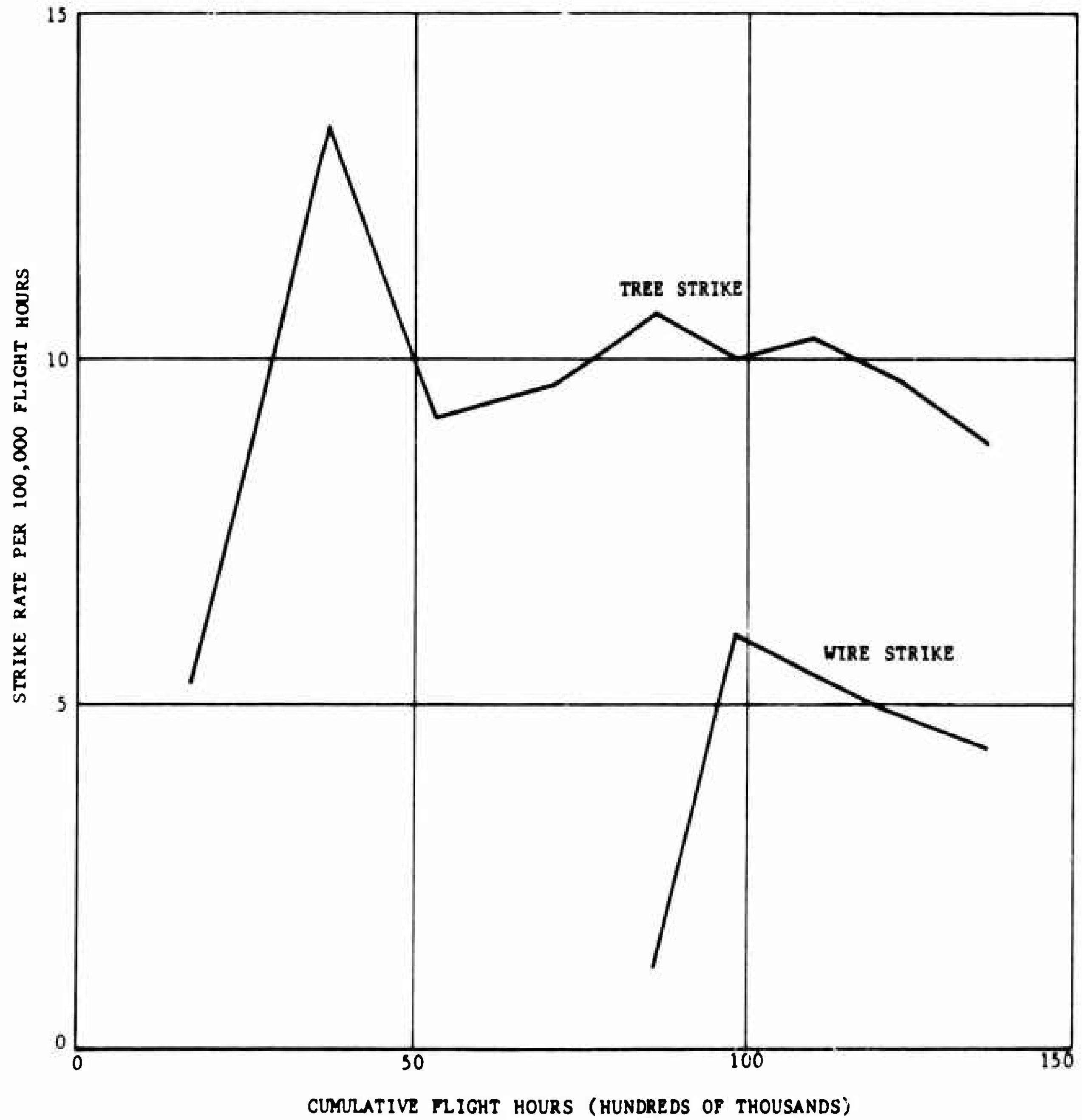


FIGURE 24. CH-21 SHAWNEE OBSTACLE IMPACT RATES

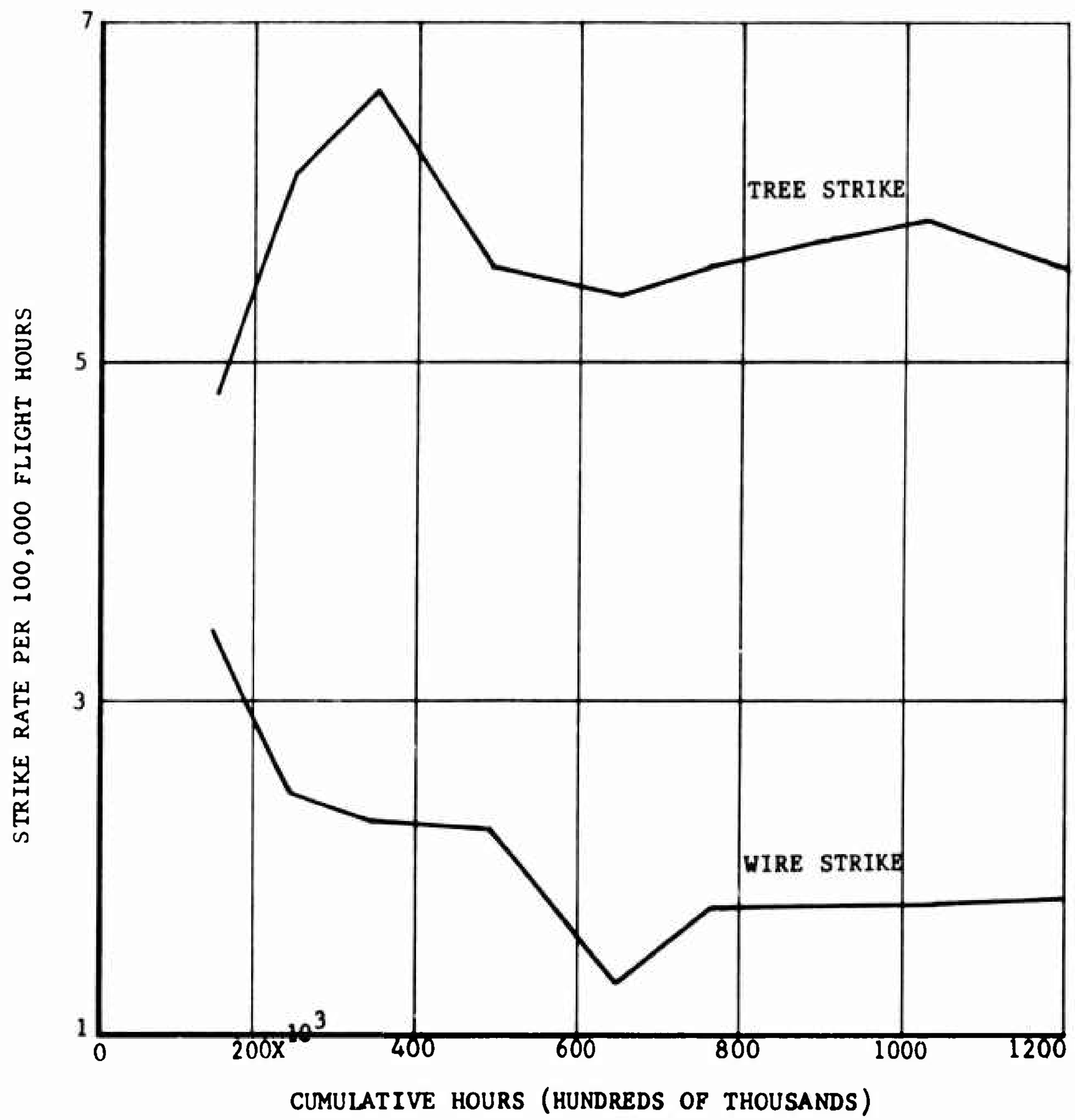


FIGURE 25. O-1 BIRD DOG OBSTACLE IMPACT RATES

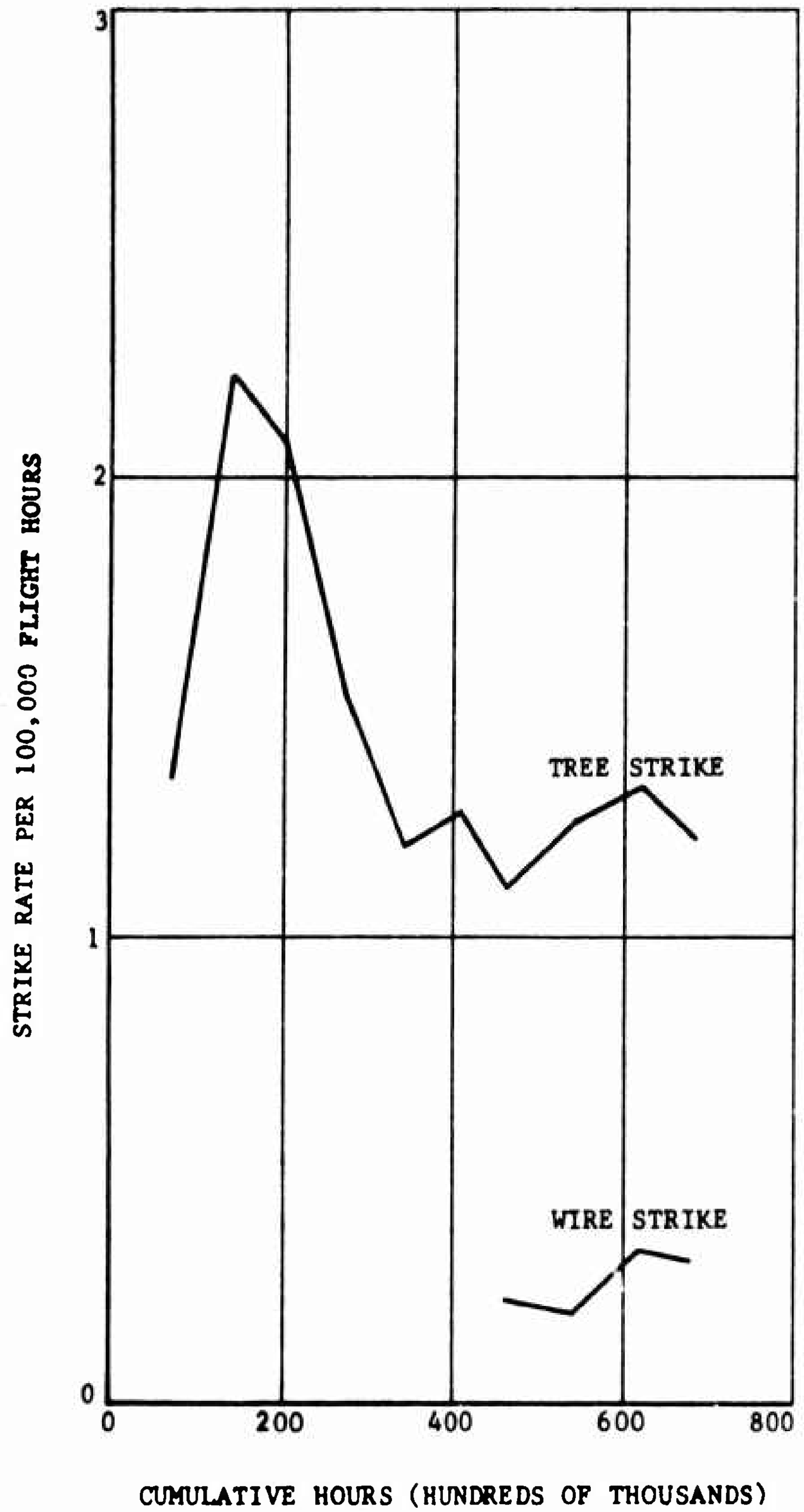


FIGURE 26. U-6A BEAVER OBSTACLE IMPACT RATES

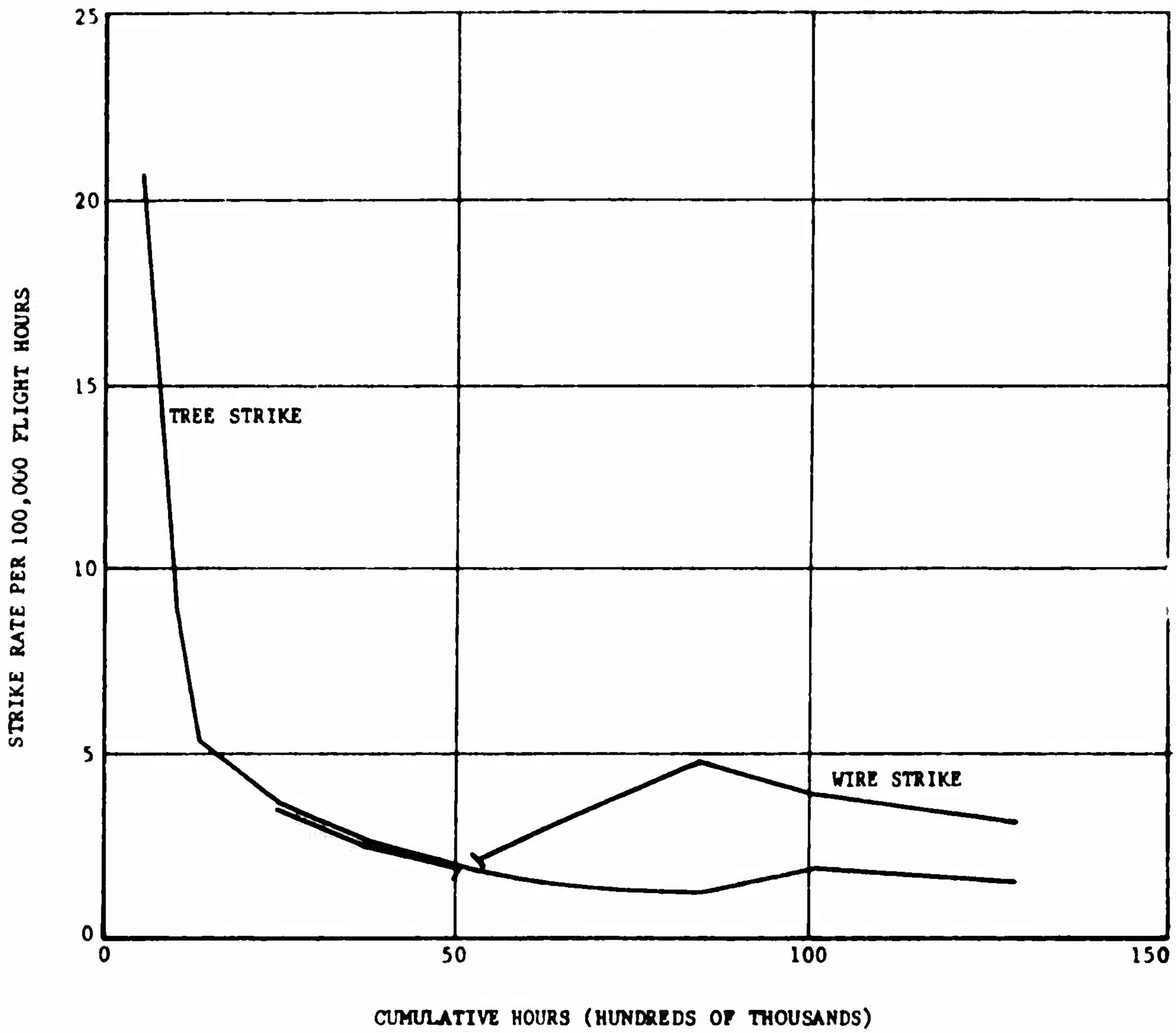


FIGURE 27. CV-2A/B CARIBOU OBSTACLE IMPACT RATES

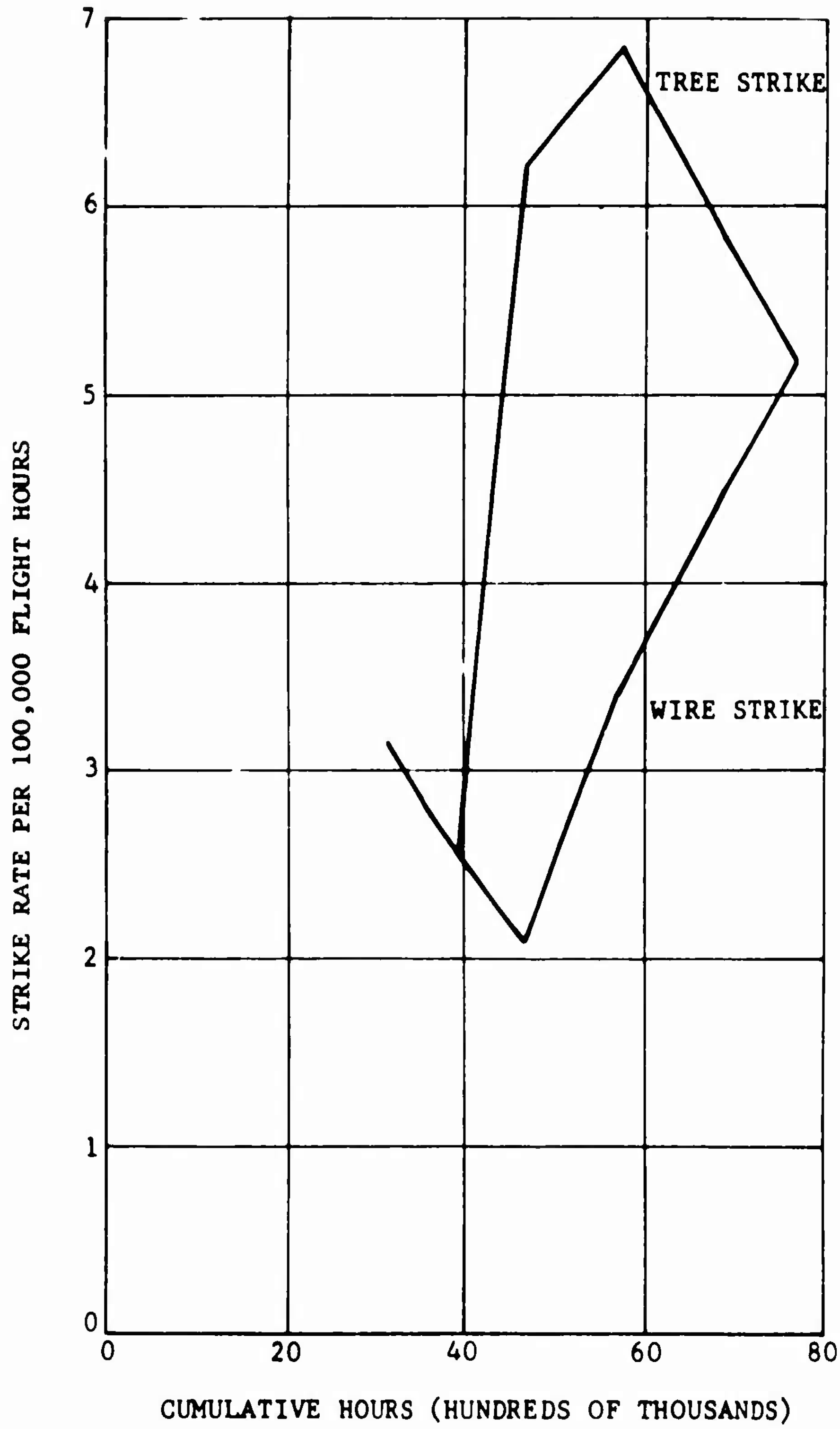


FIGURE 28. OV-1 MOHAWK OBSTACLE IMPACT RATES

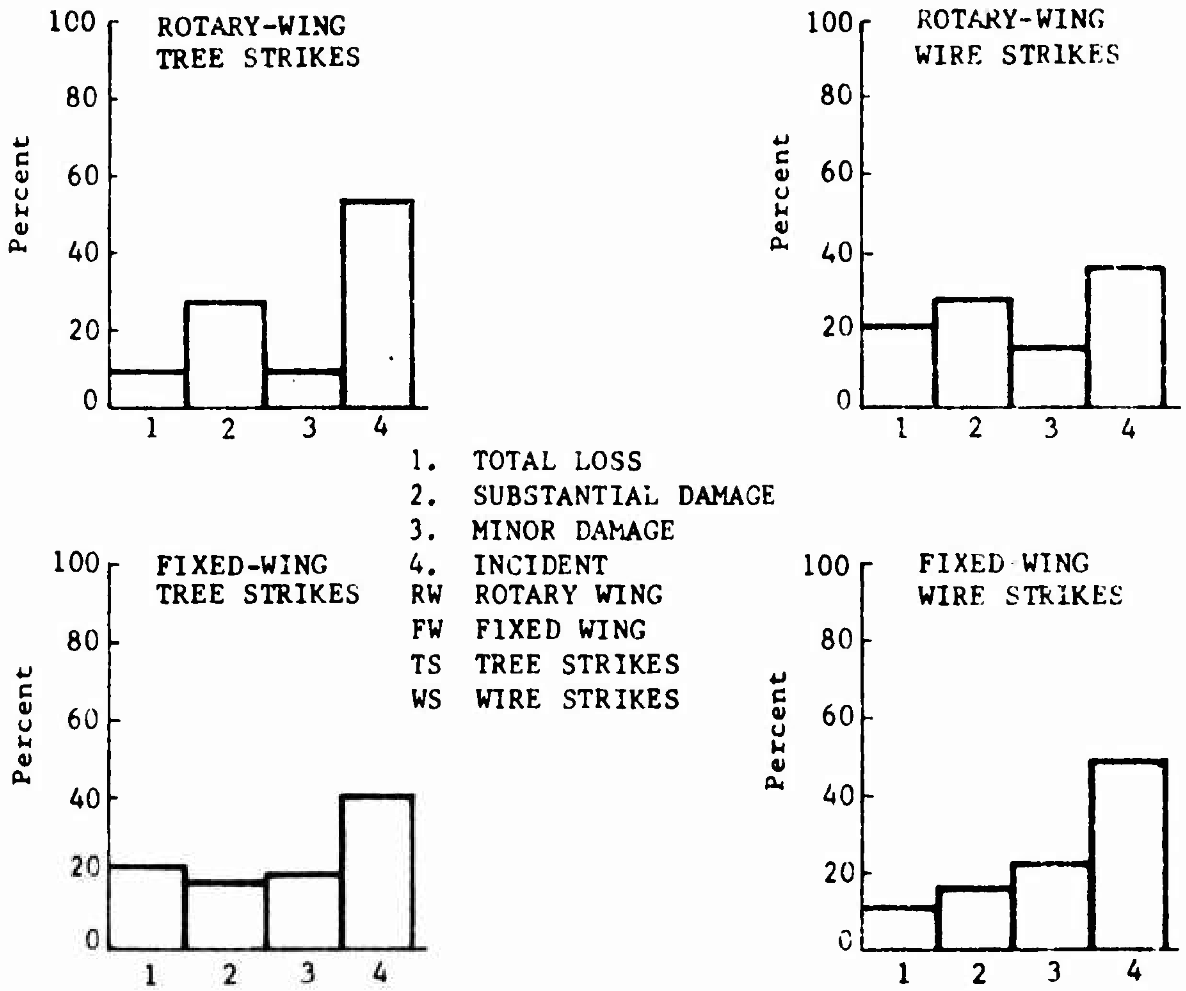


FIGURE 30. ACCIDENT CLASS DISTRIBUTIONS

TABLE 14

FIXED-WING AIRCRAFT ACCIDENTS BY CLASS

	INCIDENT	MINOR DAMAGE	SUBSTANTIAL DAMAGE	TOTAL LOSS
TREE STRIKES				
(T)0-1A,E	89	41	32	40
OV-1A,B	6	1	1	3
U-1A	0	2	1	4
U-6A	7	5	10	7
U-8D,F	-	-	1	1
CV-2A,B	4	1	1	-
C-126	-	-	2	-
WIRE STRIKES				
(T)0-1A,E	29	15	6	7
OV-1A,B	27	1	-	1
U-1A	1	-	1	-
U-6A	4	1	2	-
U-8D,F	1	-	-	1
CV-2A,B	3	-	-	-
C-126	-	-	-	-

TABLE 15

ROTARY-WING AIRCRAFT ACCIDENTS BY CLASS

	INCIDENT	MINOR DAMAGE	SUBSTANTIAL DAMAGE	TOTAL LOSS
TREE STRIKES				
OH-13	73	22	47	20
OH-23	46	2	21	2
UH-1	37	-	11	9
UH-19	53	7	6	5
CH-21	12	6	37	3
CH-34	38	10	10	8
CH-37	3	-	3	1
CH-47	1	1	-	1
WIRE STRIKES				
OH-13	30	21	35	29
OH-23	24	4	17	7
UH-1	3	-	5	2
UH-19	5	2	3	5
CH-21	11	2	2	2
CH-34	8	4	3	1
CH-37	-	-	-	-
CH-47	-	-	-	1

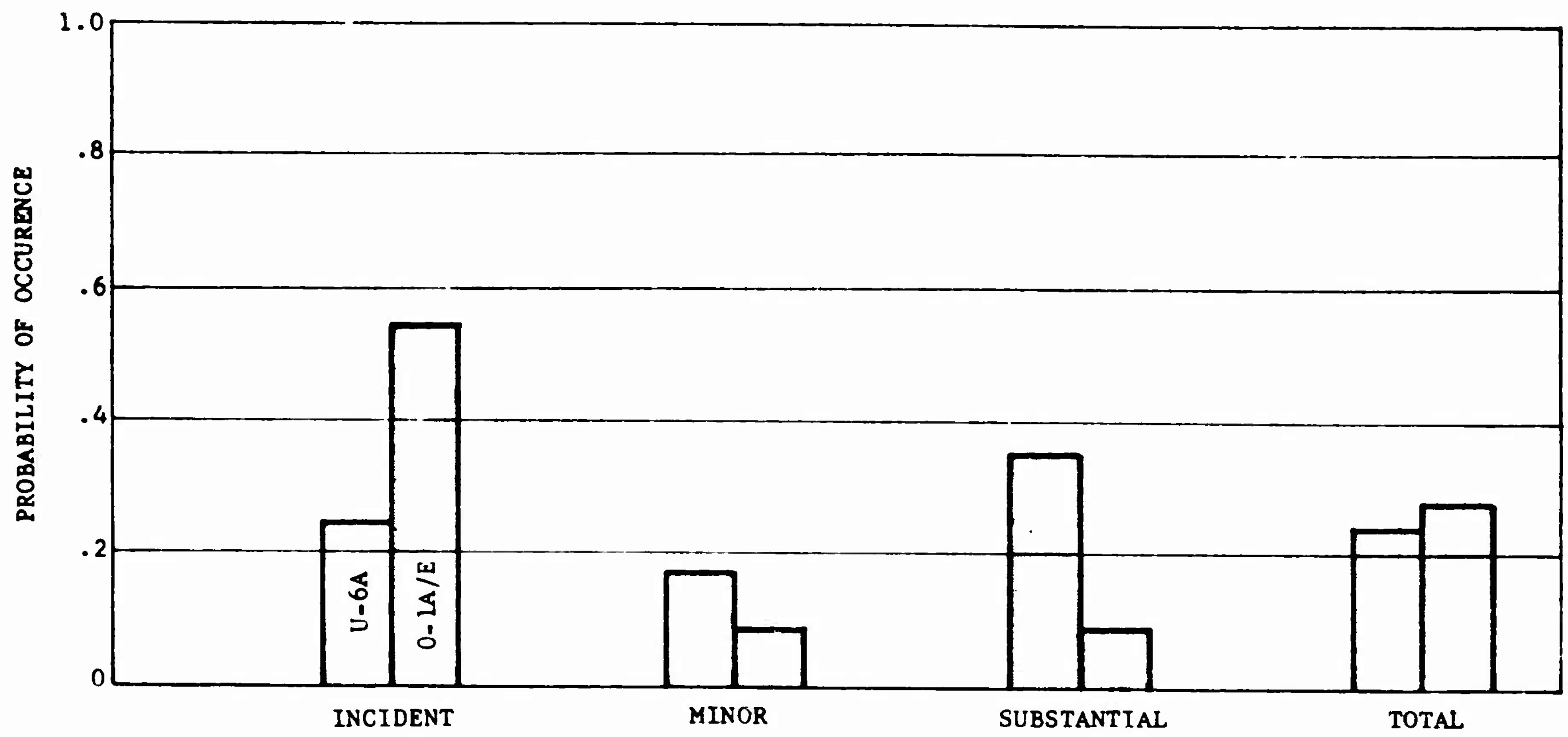


FIGURE 31. U-6A, 0-1 TREE STRIKE ACCIDENT CLASS DISTRIBUTIONS

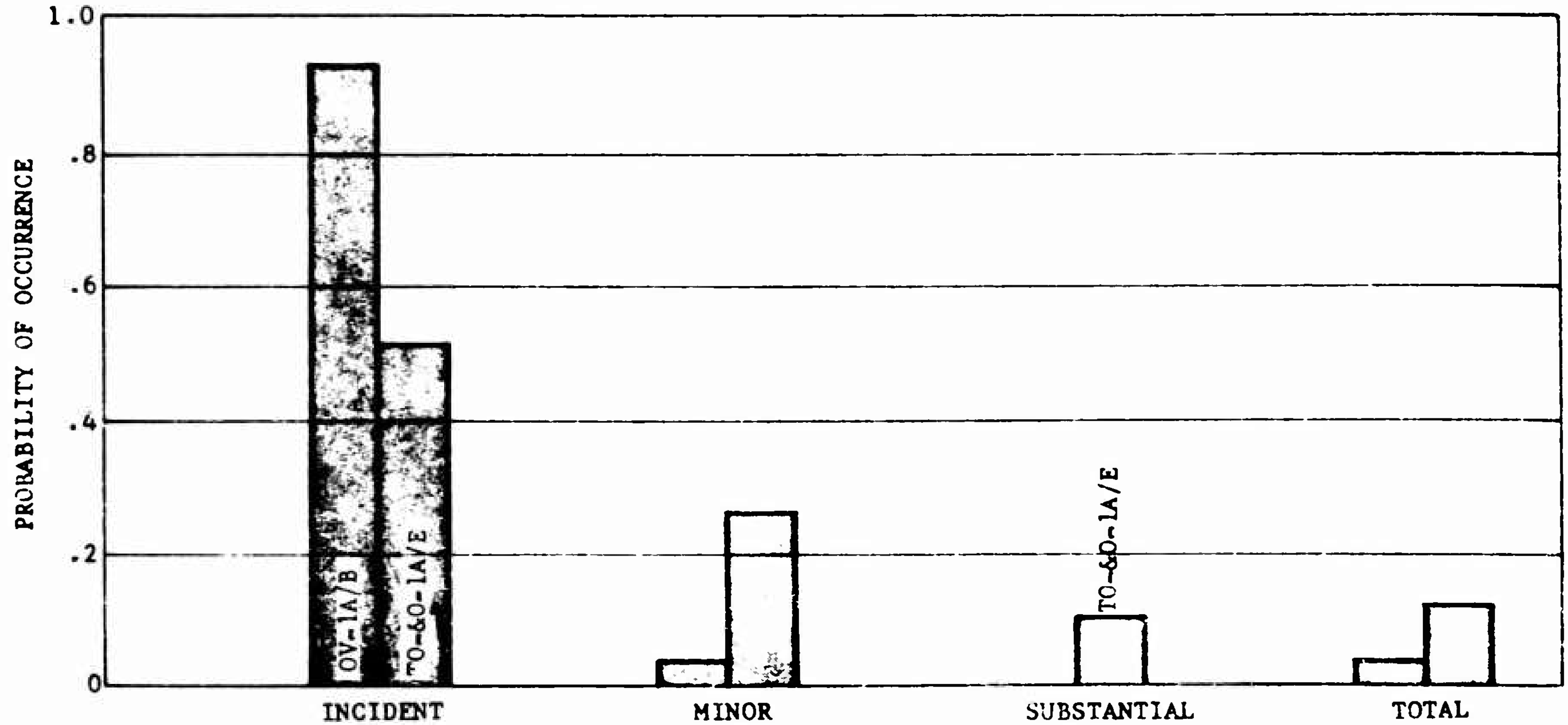


FIGURE 32. OV-1, O-1 WIRE STRIKE ACCIDENT CLASS DISTRIBUTIONS

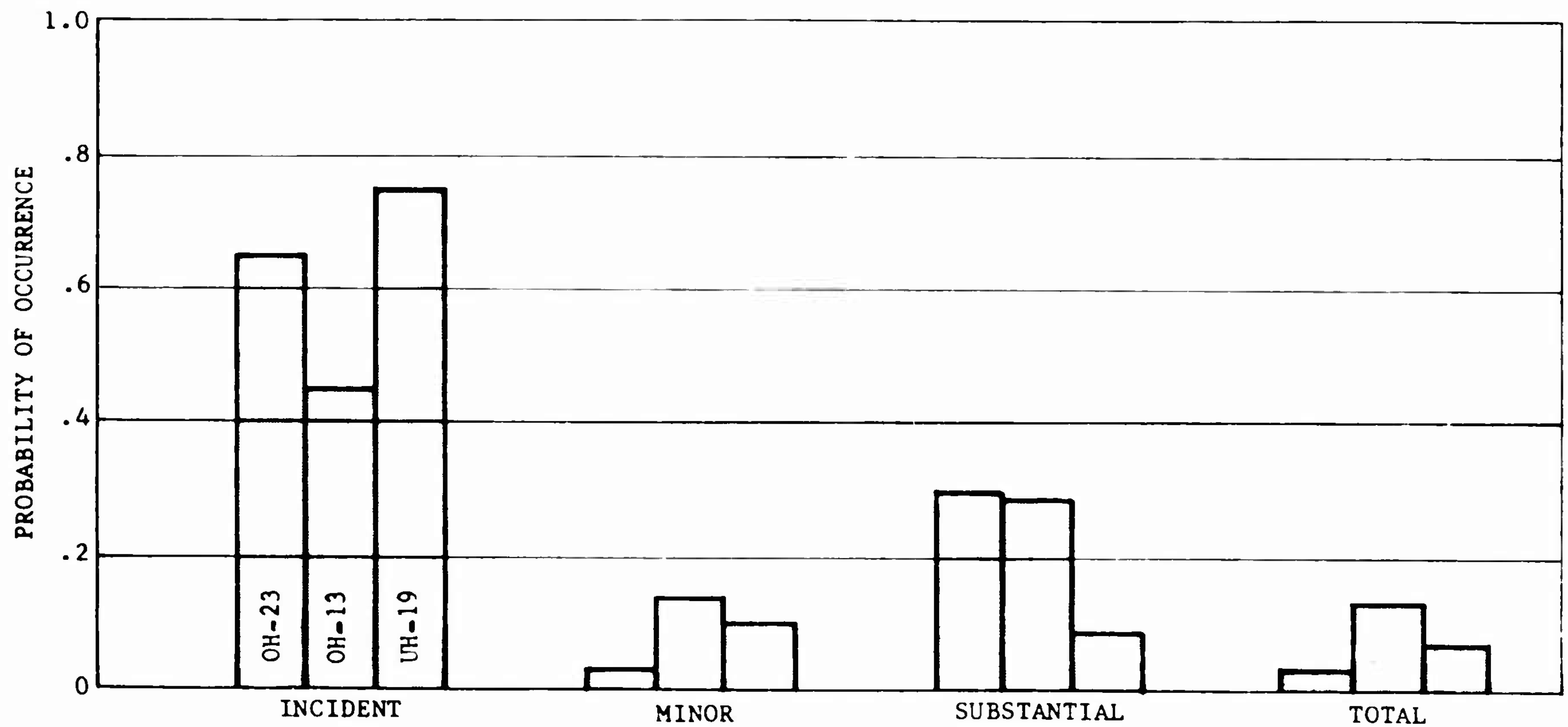


FIGURE 33. OH-23, OH-13, UH-19 TREE STRIKE ACCIDENT CLASS DISTRIBUTIONS

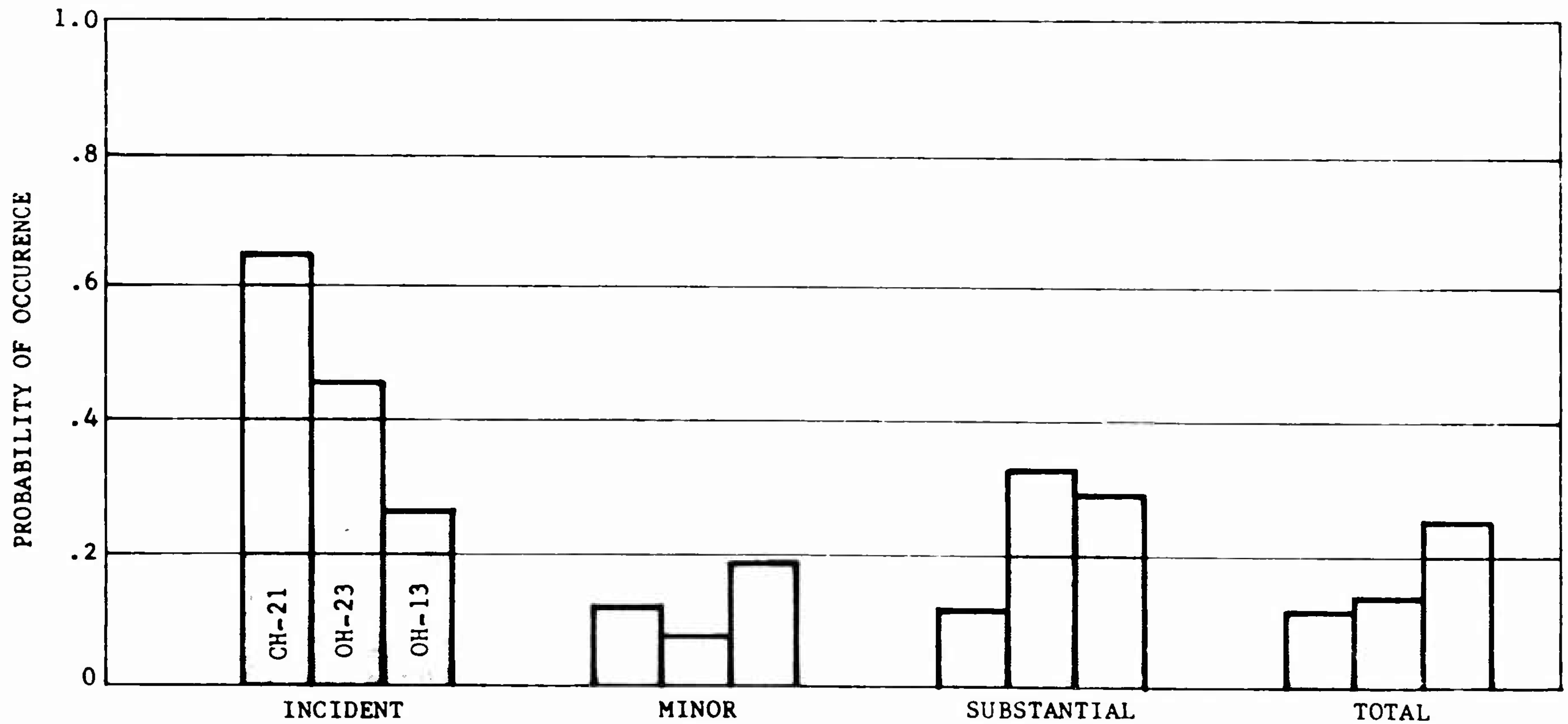


FIGURE 34. CH-21, OH-23, OH-13 WIRE STRIKE ACCIDENT CLASS DISTRIBUTIONS

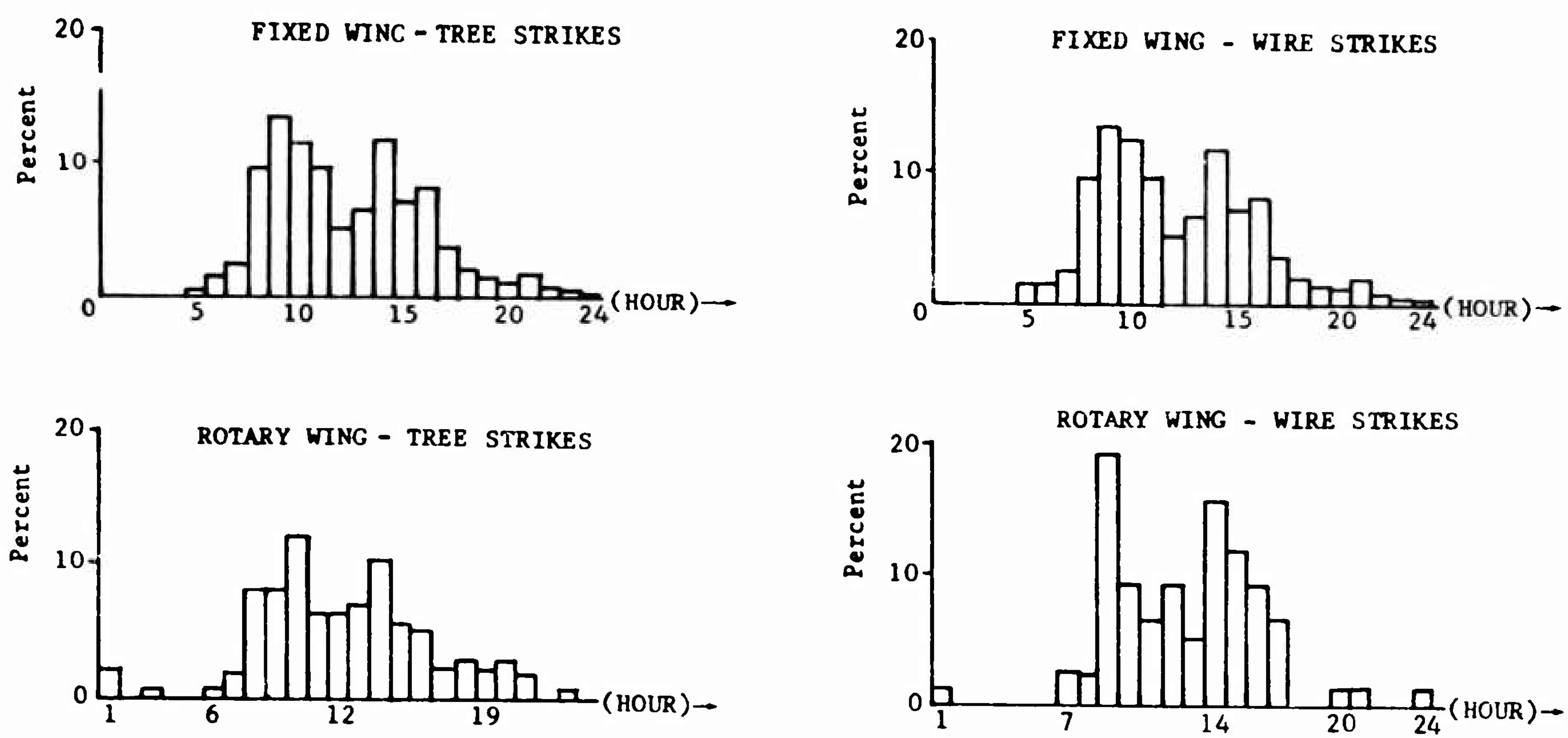


FIGURE 35. OBSTACLE IMPACT DISTRIBUTIONS BY TIME OF DAY

ticularly to the time of day. The peaks at 9 a.m. and 2 p.m. are probably the hours of highest aircraft usage. The period after 8 p.m. and before 7 a.m. involves a very limited amount of aircraft operation and with reduced low level operation, impacts occur mainly during takeoff and landing. Intuitively, it is expected that the accident rates would increase with darkness and reduced visibility, but the data on flight hours are not presented according to the time of day so no correlation with time of day is possible. The only information that relates daytime/nighttime aircraft operation is the U.S. Navy statistics, which show that night carrier landing accidents occur at 3 to 5 times the rate of day carrier landing accidents.

PHASE OF OPERATION

Trees constitute the greatest hazard to low-level flight primarily because of their greater frequency of occurrence in nature as opposed to man-made obstructions such as wires. Obviously a wire is more difficult to detect visually and in sufficient time to take evasive action. This is particularly applicable to higher performance aircraft such as the OV-1. Obscurations to visibility and viewing against ground rather than sky backgrounds serve to compound the problem. As seen on Figure 36, fixed-wing aircraft collisions with trees occur principally during the landing phase, with a comparatively even distribution of accidents being spread over the takeoff, in-flight,and go-around phases of flight. Rotary-wing aircraft tree strikes appear to follow an even distribution for all phases including the hover phase. In respect to wire strikes, both types of aircraft have a similar pattern of accident distribution, with the preponderance of helicopter collisions being experienced in the in-flight phase.

Figure 36 shows that 25 percent of the rotary-wing impacts with trees or wires occur during the landing phase and that 50 percent of the fixed-wing tree strikes and 35 percent of the fixed-wing wire strikes occur during landing. It appears, therefore, that a glide slope indicator could reduce these landing accidents by a significant number.

PILOT CAUSE FACTORS

The distribution of the tree strikes and wire strikes over the recorded pilot cause factors are shown in Table 16. It is apparent that two of the listed pilot cause factors account for 50 percent, or more, of the occurrences in every one of the four accident categories. These two major cause factors are: (1) pilot misjudged distance, altitude, or position, and (2) pilot failed to see object. The errors in judgment are much more frequent in the tree strikes, while the wire strikes were more often attributed to lack of visibility. This again indicates a need for additional positional information while flying in close proximity to trees, and for a visibility aid during all low-altitude flight. Further examination of the "misjudged" factor shows that the two subfactors occurring most frequently, other than "undetermined", are:

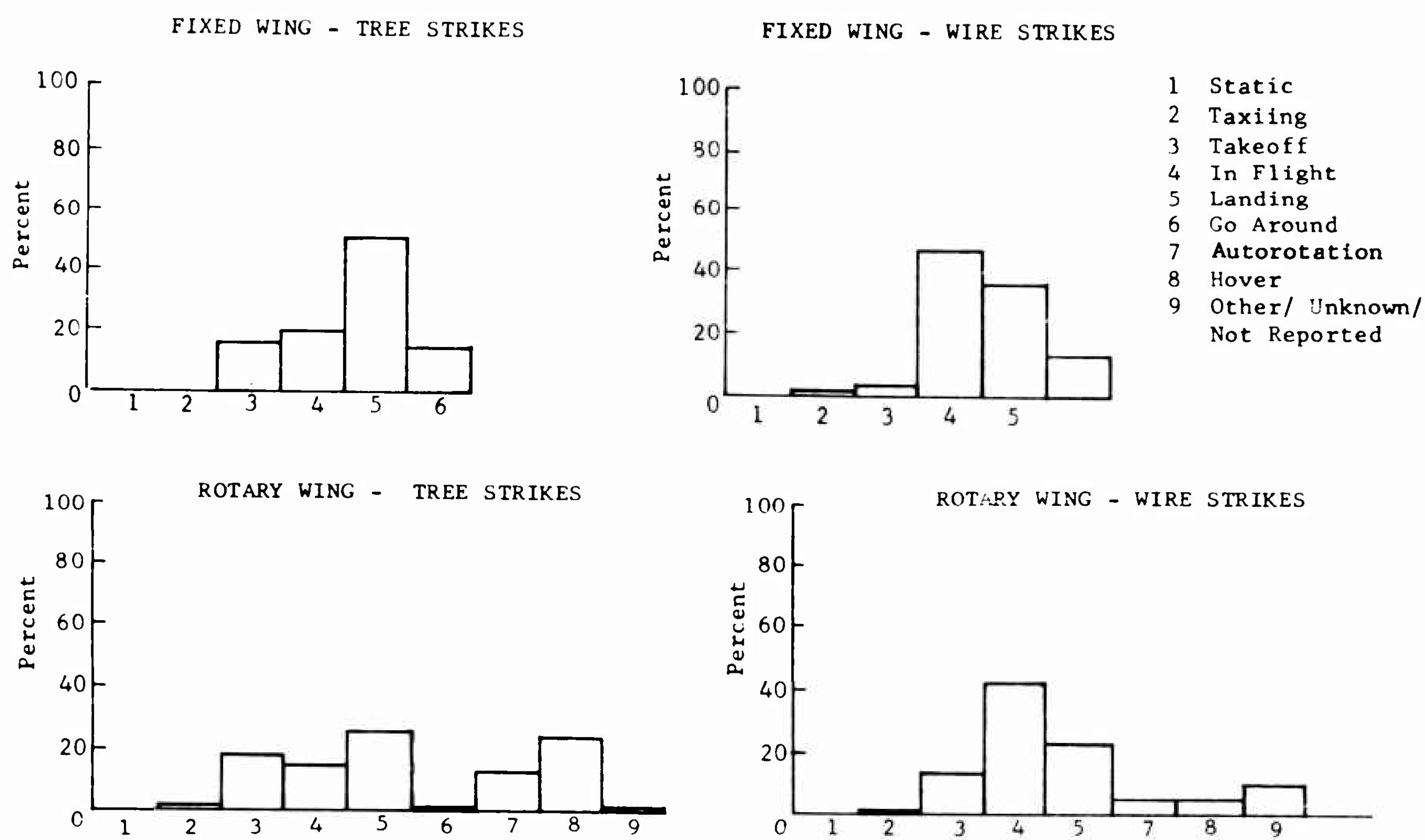


FIGURE 36. OBSTACLE IMPACT DISTRIBUTIONS BY PHASE OF FLIGHT.

TABLE 16

DISTRIBUTION OF OBSTACLE STRIKES BY PILOT CAUSE FACTORS

PILOT CAUSE FACTORS	ROTARY-WING TREE STRIKES	ROTARY-WING WIRE STRIKES	FIXED-WING TREE STRIKES	FIXED-WING WIRE STRIKES
Misuse of Power Plant Controls	11	1	24	6
Misuse of Brakes/Flight Controls, Etc., on Ground	-	-	14	2
Improper Use of Flight Controls in Air	30	8	11	2
Exceeded Stress Limits	1	-	1	-
Failure To Compensate for Wind	10	1	18	1
Misjudged Distance, Altitude, Position	252	71	144	36
Improper Level-Off	10	1	14	1
Failed to Maintain Flying Speed	40	2	11	4
Improper Use of, and/or inattention to, Fuel System	7	-	2	-
Failed To See Object	146	178	50	52
Improper Instrument Procedures	-	-	-	1
Violation of Air Discipline	13	20	15	6
Inadequate Flight Preparation	21	15	5	-
Exceeded Ability and/or Experience	13	1	6	2
Improper Use of Miscellaneous Equipment	3	-	-	-
Physical Condition of Pilot	12	5	5	-
Selected Unsuitable Terrain	19	9	5	4
Failed to Initiate Go-Around or Attempted Too Late	5	3	20	5
Miscellaneous Factors	60	35	29	3
Failed To Supervise Flight Properly	31	7	29	6
Became Lost	-	-	-	2
Performance Factor of Other Pilot in Aircraft	5	2	2	-
Totals	689	359	405	133

1. Low in landing approach

2. Used poor landing technique in general

It is interesting to note that none or very few occurrences of tree strikes or wire strikes were attributed to:

1. Improper instrument procedures

2. Exceeding stress limits

3. Becoming lost

4. Improper use of miscellaneous equipment

5. Improper use of, and/or inattention to, fuel system

The very low frequency with which these factors occur as causes would tend to validate training procedures in instruments, flight maneuvers, navigation, and the use of on-board equipment.

OTHER PERSONNEL CAUSE FACTORS

In the category of otherpersonnel as contributors to collision accidents, the largest percentage, 50 to 60 percent, are in the supervisory category. As seen in Table 17, the next significant category of other personnel are found to be in the administrative field. Those personnel in supervision appear to be amenable to simple correction and could be a source of reduced accident occurrence. For example, insuring that current NOTAMS are available, that approach patterns to air facilities are cleared of all obstructions, that hazards are clearly marked, and that proper flight preparations are executed, are typical areas in which improved supervision would pay dividends.

It is noted from Table 17 that none of these accidents are due to enemy personnel. No data were available on combat losses or the effect of combat conditions on tree strikes and wire strikes.

MAJOR COMMAND

The tree strikes and wire strikes were examined to evaluate the relative differences of operational areas. Table 18 shows the recorded impacts for each numbered Army area, overseas command, and aviation school.

The Third Army area has the greatest number of rotary-wing tree strikes, rotary-wing wire strikes, and fixed-wing tree strikes. USAREUR has the highest number of fixed-wing wire strikes. No flight hours data were available to compute impact rates for each area and aircraft model. Since tree strikes and wire strikes are a direct function of the number of operational aircraft, Table 19 shows the aircraft deployment by model and

TABLE 17

DISTRIBUTION OF OBSTACLE STRIKES BY OTHER PERSONNEL CAUSE FACTORS

DESCRIPTION	ROTARY-WING TREE STRIKES	ROTARY-WING WIRE STRIKES	FIXED-WING TREE STRIKES	FIXED-WING WIRE STRIKES
Crew	4	3	-	-
Administrative	3	12	4	1
Supervisory Personnel	18	23	15	6
Maintenance Personnel	6	3	2	-
Other Personnel	3	-	2	-
Servicing Personnel	2	-	-	-
Performance Factor of Operator of Other Aircraft	1	-	-	-
Improper Signals or Instructions: Instrument Control	1	3	-	-
Improper Signals or Instruction: Tower Personnel	-	-	1	1
Ground Personnel	2	1	1	-
Enemy Personnel	-	-	-	-
Improper Use of Special Equipment	-	-	-	-
Totals	40	45	25	8

TABLE 18

DISTRIBUTION OF OBSTACLE STRIKES BY MAJOR COMMAND

LOCATION	ROTARY-WING TREE STRIKES	ROTARY-WING WIRE STRIKES	FIXED-WING TREE STRIKES	FIXED-WING WIRE STRIKES
1st Army	8	-	2	-
2nd Army	24	21	10	6
3rd Army	148	62	66	5
4th Army	33	15	18	7
5th Army	12	6	5	4
6th Army	43	17	19	4
USAREUR	113	35	46	8
Korea	19	24	10	3
Alaska	97	1	7	-
Pacific	21	9	-	-
Comusaro	9	1	5	5
Mil. Dist. Wash.	3	-	-	-
USAAVNS	34	4	52	-
Camp Gary	-	-	2	1
Fort Wolters	28	18	-	-
Canada	-	-	-	-
Others	7	2	-	-
Totals	599	215	242	43

TABLE 19

U. S. ARMY AIRCRAFT DEPLOYMENT

	O-1	OV-1	U-6A	U-10	U-8 U-9	U-1A	CV-2	OH-13	OH-23	UH-19	UH-1	CH-21	CH-34	CH-37	CH-47
Military District Washington	9		6		20			5				24	7		
First Army	7		6		4	1		9		1		5			
Second Army	57	4	19		20	5	3	26	12	8	19	11	16		1
Third Army	132	42	37	20	15	4	67	279		8	301	4	30	16	57
Fourth Army	59	4	18		16	2	6	97	3	23	4	7	11	9	
Fifth Army	38	6	17		12	3		23	47		45				
Sixth Army	26	9	8		9	10		39	1		11				
Army Air Defense			13		13			6	44	12					
Class II Installation	73	21	48		55	38	4	99	77	30	53	87	11	4	4
Armored School										156	128				1
Aviation School	205	18	86		3	1	12	31	24			5	16	1	
Fort Wolters	3		2						207						
Europe	230	47	137		42	34		239	16		117		249	32	
Pacific	131	20	96		36	29	43	3	188		321	65		24	
Alaska	5	4	9		3	16					10	33			
Canada	7		14		5	14		7	20	5					
Army Reserve	79		4			3		11	31						
National Guard	478		94		1			4	292	4					
World Wide	1539	175	614	20	254	160	135	878	962	247	1009	241	340	86	63

command area. The aircraft quantities shown are as of January 1965.

WEATHER

Weather conditions were considered as cause factors in 10 to 20 percent of the tree strikes and wire strikes. Of these, the most frequently noted conditions were: unfavorable wind gusts, updrafts, turbulence, downdrafts, etc; density; altitude; and rain. From Table 20, wind is considered to be the weather condition most likely to cause an obstacle impact in low-altitude flight and must be evaluated in establishing design requirements for an obstacle-avoidance warning system.

PILOT EXPERIENCE

Pilot experience correlation with obstacle strikes shows in Figure 37 that 60 to 70 percent of the events involve pilots having less than one year of experience; i.e., they have been rated pilots, in either fixed-wing or rotary-wing, for less than one year. From Table 21, 40 to 60 percent of these pilots were nonrated and 30 to 40 percent were rated only in the type of aircraft in which the event occurred; i.e., rotary-wing or fixed-wing. Fifteen to twenty percent of the obstacle strikes involved pilots qualified in both fixed-wing and rotary-wing aircraft. Of the rotary-wing obstacle strikes, 50 to 60 percent of the pilots had less than 100 hours of rotary-wing experience.

Most of the remaining strikes involved pilots with less than 1000 hours of experience. The fixed-wing obstacle strikes involved pilots with less than 100 hours of fixed-wing time on 50 to 55 percent of the occurrences. The experience level of the remaining pilots (fixed-wing obstacle strikes) is quite evenly distributed over the range from 100 to 2000 hours, as shown on Figures 38 and 39.

MISSION

Table 22 shows that the missions on which the low-altitude obstacle strikes occurred are divided approximately into two-thirds training and one-third administrative. The training mission occurrences were largely student training and pilot proficiency training (approximately 2:1). The administrative missions were listed as "undetermined" or "transportation of personnel" (approximately 3:1). "Test flights" and "other" missions were involved in a few of the obstacle strikes, and, as previously noted, no combat missions were recorded.

TRAINING

Training factors related to the obstacle strikes are primarily described as lack of experience in the type of aircraft, inadequate training for accident cause, and lack of emergency procedures training or survival/rescue training.

TABLE 20

DISTRIBUTION OF OBSTACLE STRIKES DUE TO WEATHER CONDITIONS

	ROTARY-WING		FIXED-WING	
	TREE STRIKES	WIRE STRIKES	TREE STRIKES	WIRE STRIKES
Rain	3	6	3	1
Fog	8	2	3	-
Sand, Dust, Smoke, or Haze	7	3	1	2
Snow	2	-	2	-
Sleet or Hail	-	-	-	-
Wind (unfavorable in landing, taxiing, taking off)	7	1	8	4
Icing of Wing or Propeller	-	-	-	-
Carburetor Ice	1	-	2	-
Thunderstorms	1	1	-	-
Turbulence	5	1	4	1
Clouds	-	-	2	-
Lightning or Static Discharge	-	-	-	-
Updraft, Downdraft, & Winds Aloft	11	-	5	1
Low Ceiling	-	3	2	3
Sun Glare	3	5	1	2
Density Altitude	12	1	2	-
White-out	1	-	-	-
Gust	11	1	4	-
Marginal/Adverse	3	-	1	-
Not Considered a Factor	412	195	205	62
Undetermined	-	1	3	1
Totals	487	220	248	77

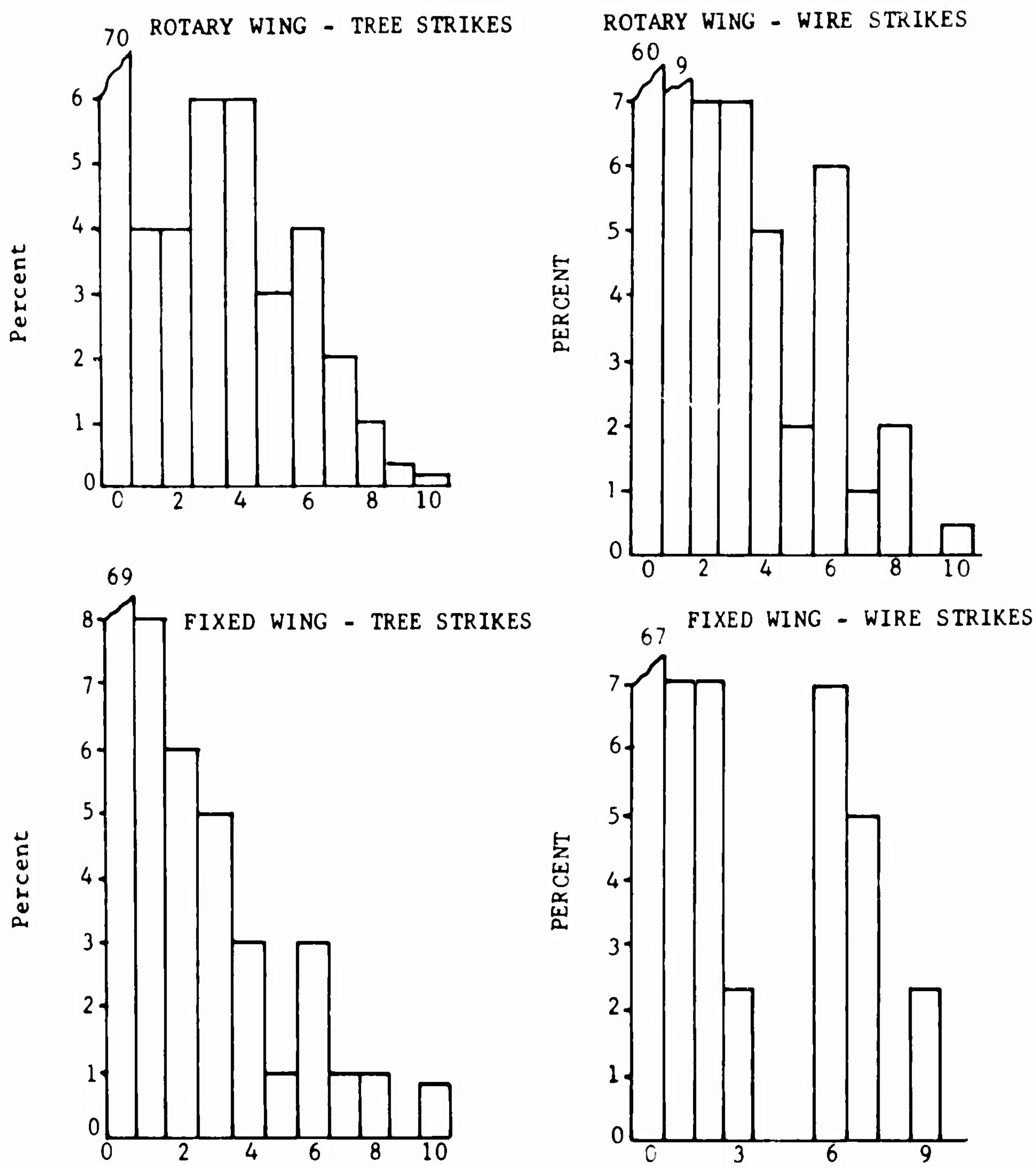


FIGURE 37. OBSTACLE IMPACT DISTRIBUTIONS
BY PILOT YEARS OF EXPERIENCE.

TABLE 21

DISTRIBUTION OF OBSTACLE STRIKES
BY PILOT QUALIFICATIONS

PILOT QUALIFIED	ROTARY-WING TREE STRIKES	ROTARY-WING WIRE STRIKES	FIXED-WING TREE STRIKES	FIXED-WING WIRE STRIKES
Fixed-Wing Only	9	8	72	18
Rotary-Wing Only	152	63	3	-
Combination	96	48	33	7
Nonrated	327	94	122	18
Total	584	213	230	43

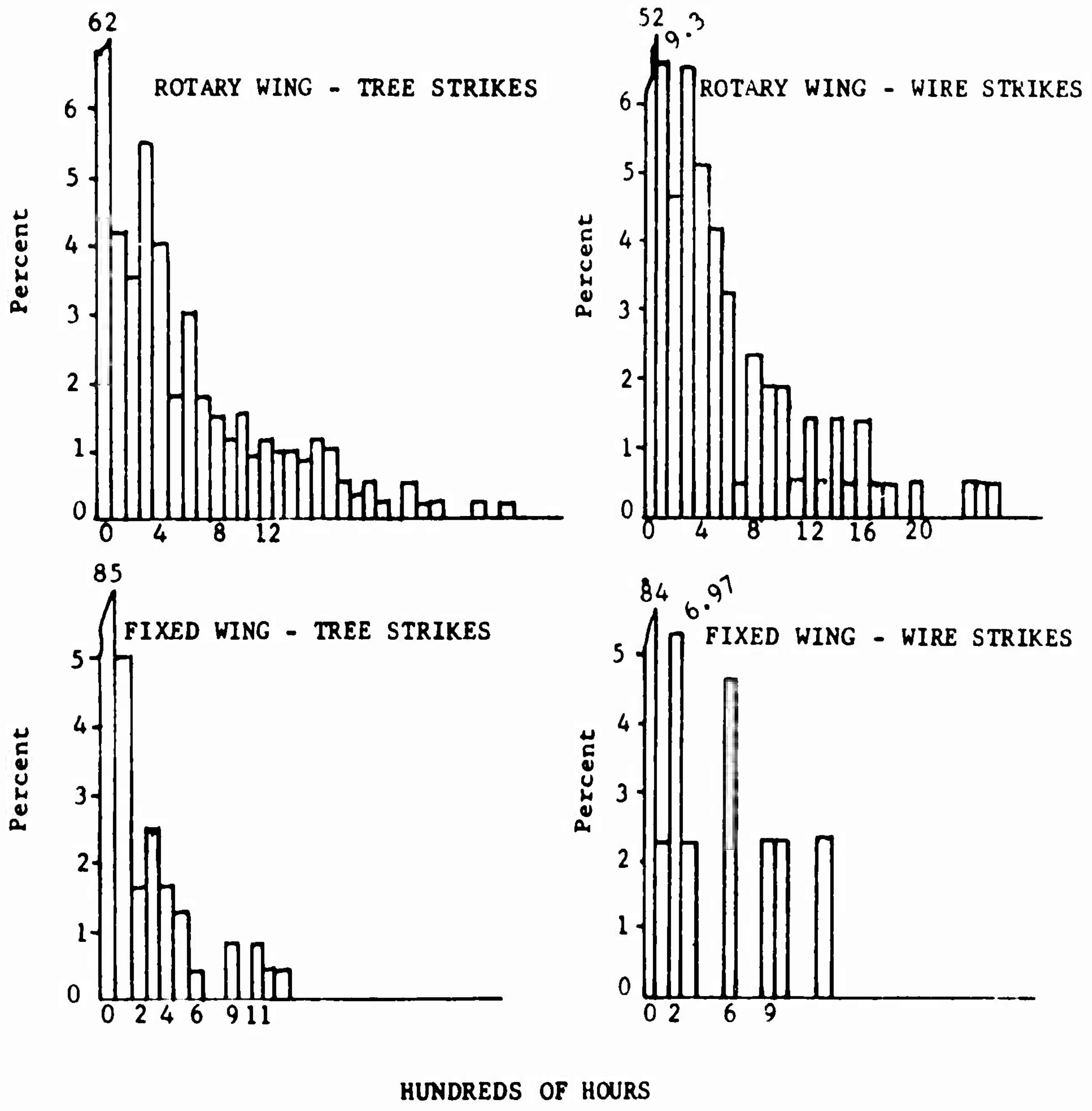


FIGURE 38. OBSTACLE IMPACT DISTRIBUTIONS BY PILOT ROTARY-WING TIME

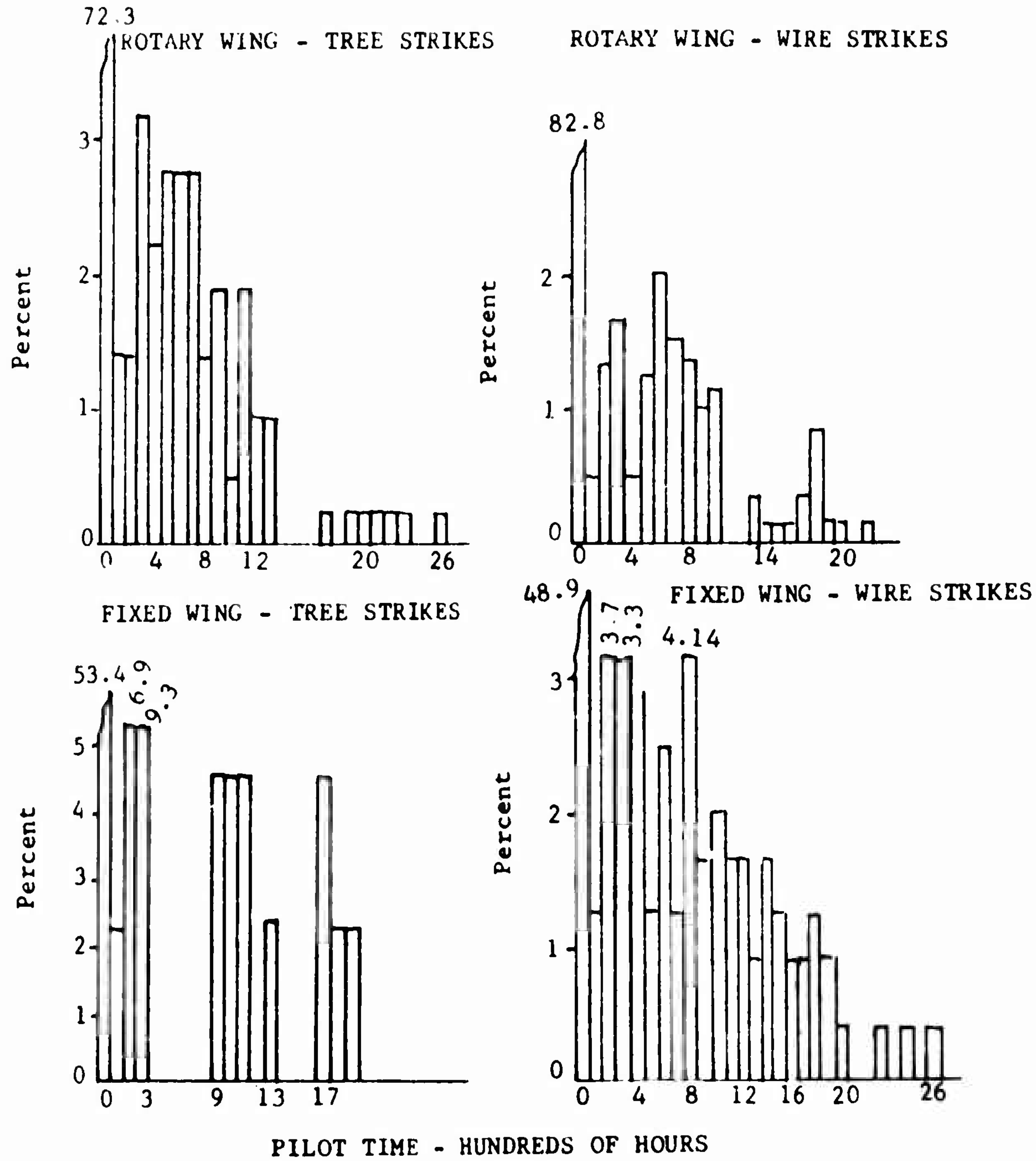


FIGURE 39, OBSTACLE IMPACT DISTRIBUTIONS BY PILOT FIXED-WING TIME

TABLE 22

DISTRIBUTION OF OBSTACLE STRIKES BY MISSION

	ROTARY-WING TREE STRIKES	ROTARY-WING WIRE STRIKES	FIXED-WING TREE STRIKES	FIXED-WING WIRE STRIKES
TRAINING:				
Proficiency	51	31	42	20
Student	132	30	127	18
Tactical	43	24	20	13
Transition	33	6	8	-
Maneuver/Field	17	3	3	1
Other	-	1	-	-
Undetermined	1	1	2	-
	277	96	202	52
ADMINISTRATIVE:				
Ferry	2	10	4	-
Evacuation	4	3	-	-
Demonstration	19	5	5	1
Search and Rescue	5	6	1	1
Transportation of Personnel	48	26	13	5
Transportation of Cargo	8	2	3	2
Other	18	7	4	1
Undetermined	115	65	24	16
	219	124	54	26
TEST FLIGHT:				
Regularly Scheduled	-	-	-	-
Airframe Change	1	-	-	-
Power Plant Change	-	-	-	-
Other	1	-	-	-
Undetermined	3	2	1	-
COMBAT:	-	-	-	-
OTHER:	1	2	1	-
TOTALS	512	223	257	78

PILOT FATIGUE

In an attempt to evaluate pilot fatigue as a cause factor in low-altitude obstacle strikes, pilot experience in the 24 hours, 30 days, and 90 days preceding the mishap was studied. As shown in Figures 40 through 42, 85 to 90 percent of the pilots had flown less than 3 hours in the previous 24, less than 40 hours in the previous 30 days, and less than 10 hours of night flying in the previous 90 days. Physiological factors for rotary-wing low-altitude obstacle strikes are listed as fatigue, unqualified, and visual obstructions(dust, sun, snow, etc.). The main fixed-wing physiological factor is disorientation (vertigo, IFR). Relating the physiological factors to the pilot flight time preceding the strikes, it is concluded that pilot fatigue is not a significant factor in low-altitude flight mishaps, and the "unqualified" portion of the "fatigue, unqualified" cause factor is probably predominant. The statistics suggest that fatigue begins to be significant when pilot time in the last 24 hours exceeds 7 to 8 hours for rotary-wing aircraft and 10 hours for fixed-wing aircraft.

PERSONNEL INJURIES

Review of the injuries related to low-altitude flight hazards on Table 23 shows the rotary-wing wire strikes to have the highest rate of fatalities and critical injuries and the fixed-wing tree strikes to rank second. These relate to the greatest degree of aircraft damage discussed previously under accident class. The least hazardous of the categories of obstacle strikes is rotary-wing tree strikes, from the standpoint of injury to personnel and damage to the aircraft.

TABLE 23

PERSONNEL INJURY

DESCRIPTION	ROTARY-WING TREE STRIKES	ROTARY-WING WIRE STRIKES	FIXED-WING TREE STRIKES	FIXED-WING WIRE STRIKES
No Injury	449	168	218	69
Minor Injury	27	27	22	5
Major Injury	9	2	3	2
Critical Injury	2	4	4	-
Fatal Injury	11	13	12	3
Unknown	-	-	-	-
Totals	498	224	259	79

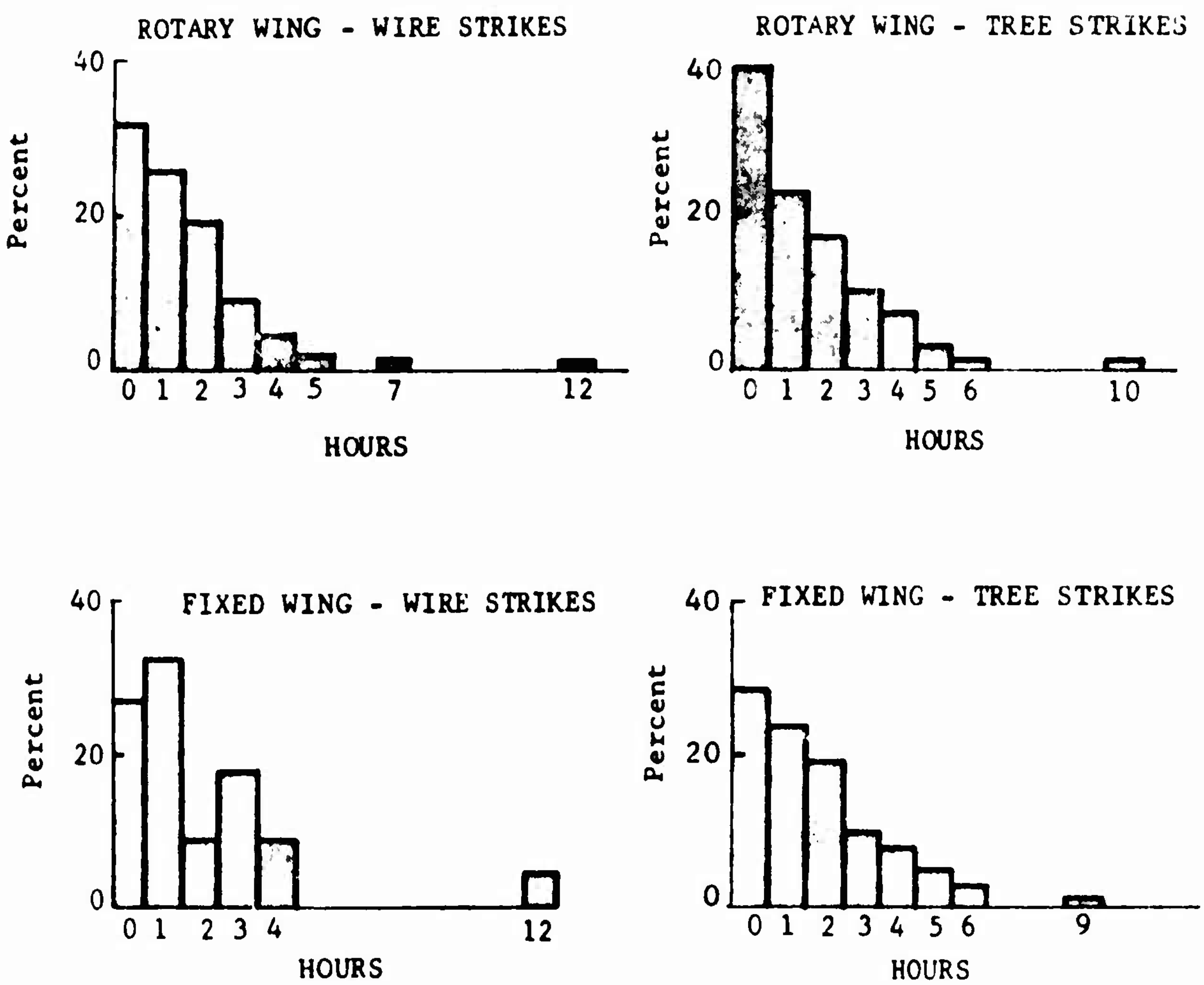


FIGURE 40. OBSTACLE IMPACT DISTRIBUTION BY PILOT TIME IN LAST 24 HOURS

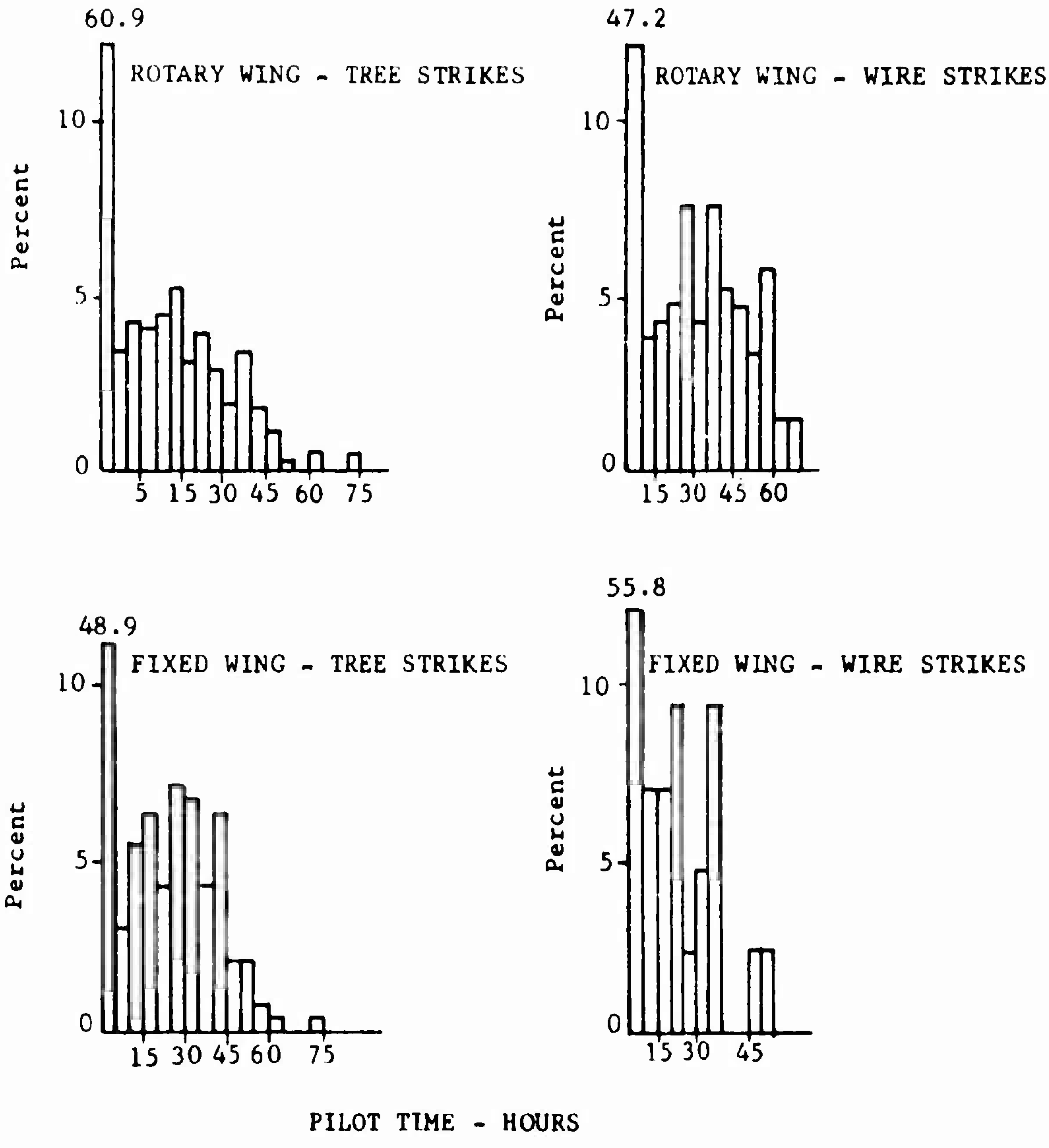


FIGURE 41. OBSTACLE IMPACT DISTRIBUTIONS BY PILOT TIME IN LAST 30 DAYS

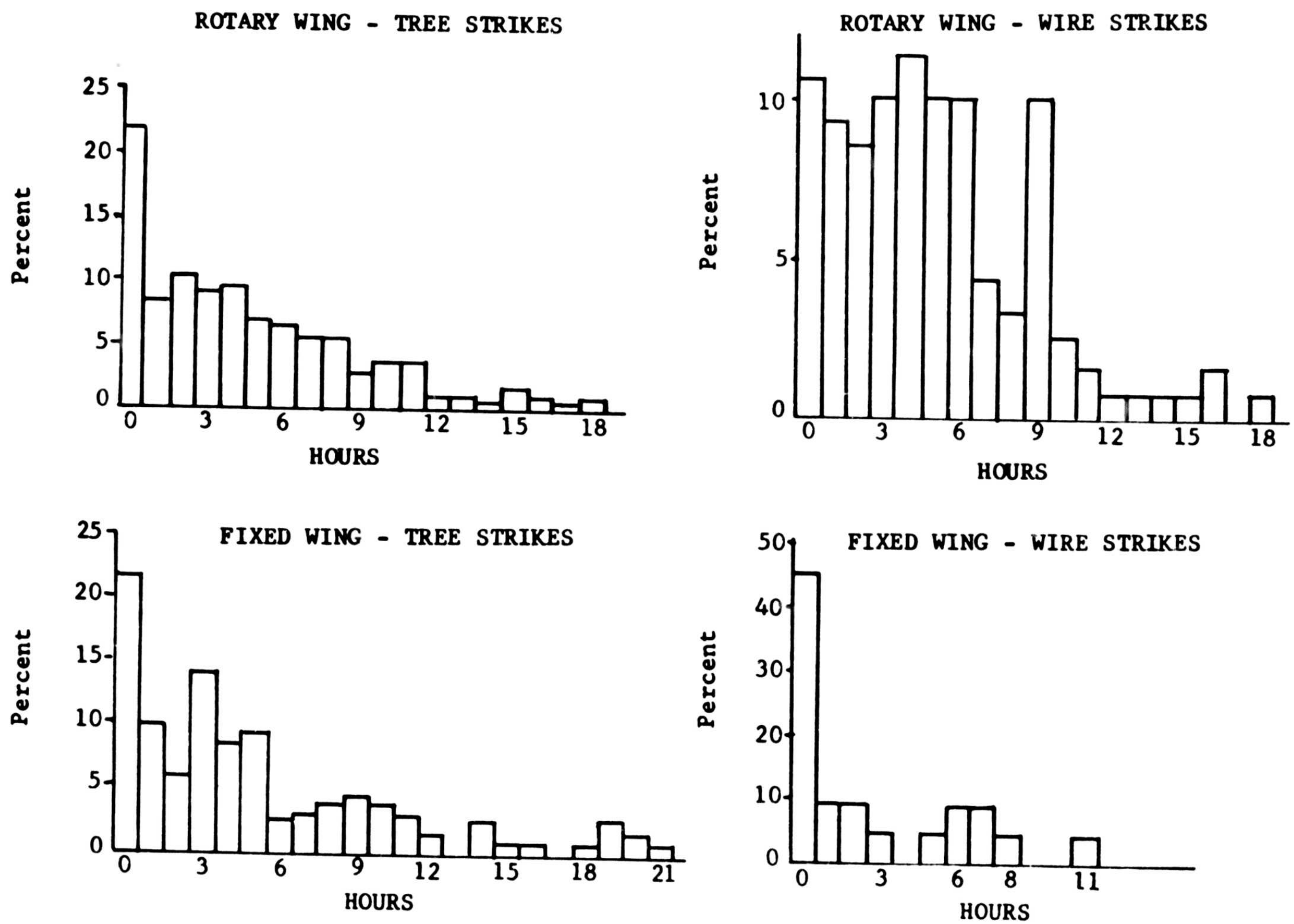


FIGURE 42. OBSTACLE IMPACT DISTRIBUTIONS BY PILOT NIGHT TIME IN LAST 90 DAYS

APPENDIX II

PASSIVE SENSOR TECHNOLOGY

MICROWAVE RADIOMETRY

Because of the relatively large beam widths (compared to optical sensors) characteristic of microwave radiometric sensors, targets of interest will generally not fill the beam. In this situation, the temperature difference between an obstacle and its background is effectively reduced by the ratio of the solid angle subtended by the target to the solid angular beam width. Hence the target-background temperature difference ΔT required for detection is related to the minimum detectable temperature T_m characteristic of the radiometer by

$$\Delta T \frac{A_o}{\frac{\pi}{4} \theta^2 R^2} = T_m$$

where A_o is the area of the target, R is the range to the target, and θ is the radiometer beam width. Alternatively, the maximum detection range can be expressed as

$$R^2 = \frac{A_o \ \Delta T}{\frac{\pi}{4} \theta^2 \ T_m} .$$

For a wire of diameter d extending across the beam at a range R, the projected area within the beam is $d \theta R$; by substitution in the above equation, the maximum detection range for a wire is

$$R = \frac{4 \ d \ \Delta T}{\pi \ \theta \ T_m} .$$

A crucial measure of radiometer performance is the effective rms temperature fluctuation at the radiometer input, T_{rms}. This parameter is related to the noise figure F, predetection bandwidth B, and integrating time τ by the expression

$$T_{rms} = \frac{A \ [(F - 1) T_o + T_A]}{\sqrt{B \tau}}$$

where T_o is 290°K, A is a constant of order 2 depending on the specific configuration of the radiometer, and T_A is antenna temperature. State-of-the-art values for T_{rms} with $\tau = 1$ second are about .2°K for a superheterodyne receiver with a traveling-wave-tube IF amplifier, and about .07°K for receivers employing traveling-wave-tube RF amplifiers. The

minimum detectable temperature T_m is usually taken to be about five or six times T_{rms}. Using .4°K for T_m, and a beam width of 2.3° (2-foot-diameter antenna at an operating frequency of 35 Gc), the maximum detection range for a 1/4-inch-diameter wire exhibiting a 50° temperature difference from its background is

$$R = \frac{4(.25 \text{ inch})(50° \text{ K})}{\pi(.04 \text{ rad})(.4°\text{K})(12 \text{ inches/ft})} = 83 \text{ feet},$$

which of course is entirely inadequate.

OBSTACLE-BACKGROUND CONTRAST

Obstacle detectability depends fundamentally on contrast between the obstacle and the background. In the case of thermal sensors, the contrast depends on obstacle and background radiometric temperature.

Table 24 presents the general contrast situation for the above obstacles as seen against the matrix of backgrounds. The table shows a wide range of expected obstacle-background contrasts because of the variety of backgrounds which must be considered. Therefore, the obstacle itself will not always be discernible on a passive sensor display. This does not rule out the application of passive sensors to the alignment problem described in the main body of this report, however.

THE INFRARED SENSOR

In the following, the detector raster is considered to be an array, or matrix, of smaller elements, each element a small detector capable of being sampled independently of the rest of the matrix. The entire detector matrix consists of $N = n \times n$ elements.

Three possibilities should be examined:

1. Obstacle larger than raster ($A_T > A_M$)

2. Obstacle larger than detector element ($A_T > A_\omega$)

3. Obstacle smaller than detector element ($A_T < A_\omega$)

where

A_T = area of obstacle

A_M = projected area in obstacle plane of entire scan pattern; i.e., area viewed by entire matrix

A_ω = area viewed by one detector element of solid angle (instantaneous field of view).

TABLE 24

SUMMARY OBSTACLE-BACKGROUND CONTRAST SITUATIONS

OBSTACLE	EMISSIVITY	BACKGROUND	INFRARED CONTRAST	MICROWAVE CONTRAST	VISUAL CONTRAST
Wires	Low	Sky, clear	Poor	Fair	Excellent
		Cloudy	Fair	Fair	Excellent
		Earth and trees	Good	Good	Poor
		Water	Good	Poor	Variable
Trees	High	Sky, clear	Good	Excellent	Excellent
		Cloudy	Fair	Good	Excellent
		Earth and trees	Fair-Poor	Poor	Poor
		Water	Poor	Poor	Good

In case 1, the size of the obstacle is such that its image is larger than the entire detector matrix, as shown in Figure 43. Here the detector matrix sees only the target; it sees none of the surrounding background. In case 2, the target image is larger than any one detector element, but smaller than the entire detector matrix. In case 3, the image of the target is so small that it does not even completely fill one detector element.

Whichever case pertains depends upon (1) the optical system, (2) the detector raster area, (3) the number of detector elements, (4) the target area, and (5) the range, R. In any case, however, the relative spectral transmission of the optical system $\tau_0(\lambda)$ must be considered, since, with the exception of the transmission losses in the optical system, all the energy incident on the collector optics is focused on the detector. Also, the relative spectral responsivity $R(\lambda)$ of each detector element, normalized to the peak responsivity, may be included to give a figure for the effective power.

In cases 1 and 2, the expression

$$dP_T = \frac{dS_\omega dS_R}{R^2} \cos\alpha_S \cos\alpha_R \int_{\lambda_1}^{\lambda_2} \tau_a(\lambda)\, \tau_o(\lambda)\, R(\lambda)\, \epsilon(\lambda)_T\, N_b(\lambda)_S\, d\lambda$$

where α_S, α_R = angles accounting for projections of the target and the collector aperture normal to the line of sight

$\tau_a(\lambda)$ = relative spectral transmission of the atmosphere

$\epsilon(\lambda)_T$ = spectral emissivity of target

$N_b(\lambda)_S$ = spectral radiance of a blackbody at the same temperature as the target

where dS_ω = projected area of the detector element in the plane of the obstacle

dS_R = area of collector

gives the effective power on one detector element in the wavelength interval λ_2 λ_1 when that element is actually viewing part of the target.

In cases 2 and 3, some of the elements are permitted to view only the background, and the effective power on one such element is given by

$$dP_B = \frac{dS_\omega dS_R}{R^2} \cos\alpha_B \cos\alpha_R \int_{\lambda_1}^{\lambda_2} \tau_a(\lambda)\, \tau_o(\lambda)\, R(\lambda)\, \epsilon(\lambda)_B\, N_b(\lambda)_B\, d\lambda$$

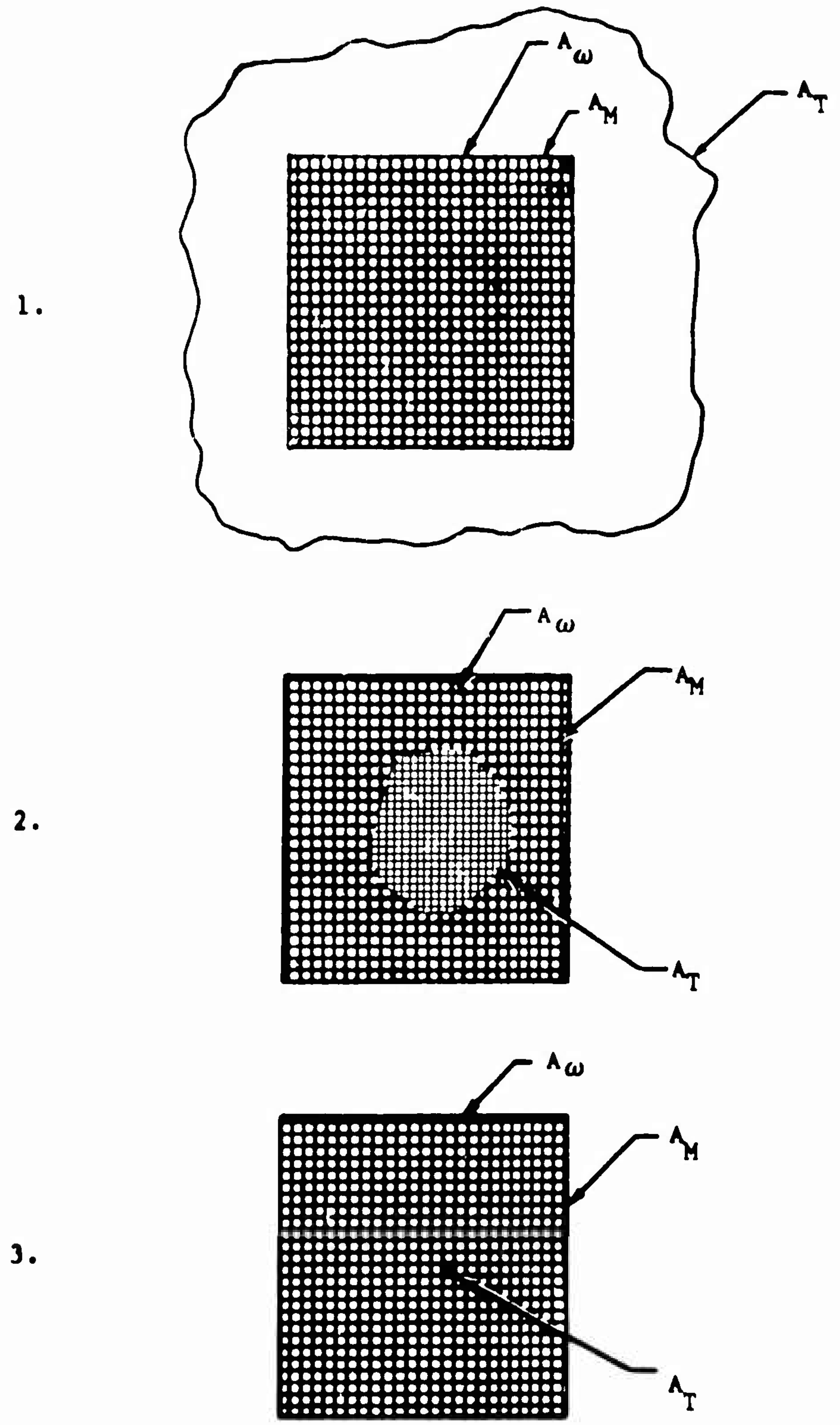


FIGURE 43. THREE POSSIBLE CASES, RELATIVE TO TARGET IMAGE AND DETECTOR SIZES.

where $\epsilon(\lambda)_B$ = spectral emissivity of background

$N_b(\lambda)_B$ = spectral radiance of a blackbody at the same temperature as the background.

In case 3, the total power is the sum of the powers contributed by the small target and that contributed by the background within the element field of view:

$$P_{S+B} = P_S + P_B$$

where:

$$dP_S = \frac{dS_S dS_R}{R^2} \cos\alpha_S \cos\alpha_R \int_{\lambda_1}^{\lambda_2} \tau_a(\lambda)\, \tau_o(\lambda)\, R(\lambda)\, \epsilon(\lambda)_S\, N_b(\lambda)_S\, d\lambda$$

$$dP_B = \frac{dS_B dS_R}{R^2} \cos\alpha_B \cos\alpha_R \int_{\lambda_1}^{\lambda_2} \tau_a(\lambda)\, \tau_o(\lambda)\, R(\lambda)\, \epsilon(\lambda)_B\, N_b(\lambda)_B\, d\lambda$$

and $dS_B = dS_\omega - dS_S$ is the area of the background.

The resulting video signals are given by the step:

$$P = P_{S+B} - P_B$$

Calculation of Infrared Sensor S/N Ratio

The detectivity, D, of a sensor is defined as

$$D = \frac{R_V}{N_{rms}} = \frac{1}{NEP}$$

where

NEP = Noise Equivalent Power

N_{rms} = rms noise output detector, volts

R_V = responsivity, volts watt^{-1} (electrical out to optical in)

Also,

$$D = \left(\frac{S}{N}\right)_{rms} \frac{1}{P_{rms}}; \left(\frac{S}{N}\right)_{rms} = DP_{rms}$$

The signal-to-noise ratio is determined by

$$S/N = D\left(P_{S_{rms}} - P_{B_{rms}}\right) = \frac{D^*}{\sqrt{a(\Delta f)}}\left(P_{S_{rms}} - P_{B_{rms}}\right)$$

where $D = \dfrac{D^*}{\sqrt{a(\Delta f)}}$ is the detectivity of the element

D^* = specific detectivity normalized with respect to element area and noise bandwidth

a = area of the detector

Δf = noise equivalent bandwidth

Note: The values of detectivities, D and D*, are normally obtained by optical chopping. If the irradiation of the detector is essentially constant, while the sensor is electrivally chopped, the rms optical power is equal to the peak power. The calculation of S/N assumes that the same D* would be obtained for optical and electrical chopping. It is also assumed that all detectors are in every way identical.

Except in case 3, the rms optical power is equal to the peak power. If the area of the detector element is unknown, it can be computed from a knowledge of the optical system employed.

SENSOR REQUIREMENTS

The following detector and optical system parameters are defined as determining sensor subsystem behavior:

1. Detector:

   n = number of image elements on side of square array

   $N = n^2$ = number of image elements per frame

   T = frame period

   $t = T/N$ = image element dwell time

   L = raster length

   W = raster width

   $A = LW$ = raster area

   $a = A/N$ = image element area

   $\Delta f \simeq N/T \simeq$ bandwidth

2. Optical System:

f = focal length

D_o = diameter of the collector

$F = F/D_o$ = relative aperture of telescope

$\omega = \Omega/n$ = angular instantaneous field of view of the dector element (analagous to beam width)

$\Omega = L/f$ = angular field of view of the matrix

The specifications of a possible infrared sensor on the basis of the above parameters are outlined in Table 25.

Substitution of numerical values into the appropriate relations given earlier shows that the signal-to-noise ratios achievable against wire obstacles at ranges of interest are inadequate. For example, even with a temperature contrast of 25°K, a minimum target diameter of 30 inches is required for detection of a cylindrical obstacle at 1500 feet with an uncooled lead-sulfide detector. Use of more sensitive detectors does not improve the situation sufficiently to make passive infrared obstacle detection practical.

TABLE 25

ELECTROOPTICAL CHARACTERISTICS OF PROPOSED OBSTACLE-AVOIDANCE IR SENSOR

DETECTOR PARAMETERS	OPTICAL SYSTEM PARAMETERS
n = 16	f = 8.2 inches
N = 256	F = 1.37
T = 1 second	T = 1 second
t = 3.9 millisec	D_o = 6 inches = 15 cm
L = 2.54 cm	Ω = 7.0 degrees
W = 2.54 cm	ω = .44 degrees = 26 arc-minutes
A = 6.45 cm^2	
a = 2.5 mm^2	
Δf = 256 cps	

Although the resolution of the sensor should not be construed to be a final design value, a notion of the sensitivity of a multichannel system is obtained.

VISUAL SENSOR

There will first be calculated the visual irradiance of an image element of a visual image sensor from a wire obstacle as a function of obstacle range and reflectivity, and ambient illumination level. As an example of a visual sensor for the approximate calculation, the 1/2-inch vidicon will be taken with an f:2 telescope. The resolution is assumed to be 400 lines (Table 26).

TABLE 26

ELECTROOPTICAL CHARACTERISTICS OF A PROPOSED VISUAL OBSTACLE-AVOIDANCE SENSOR

DETECTOR PARAMETERS	OPTICAL SYSTEM PARAMETERS
$n = 400$	$f = 5.6$ cm
$N = 1.6 \cdot 10^5$	$F = 2$
$T = 1$ second	$D_o = 2.8$ cm
$t = 6.25$ microseconds	$\Omega = 4.9$ degrees
$L = .188$ inch $= 4.77$ mm	$\omega = .21$ milliradians
$W = .25$ inch $= 6.33$ mm	
$A = .302\ cm^2$	
$a = 1.89 \cdot 10^{-6}\ cm^2$	
$\Delta f = 1.6 \cdot 10^5$ cps	

The contrast will be defined as

$$\frac{\Delta B}{B} = \frac{B_S - B_B}{B_S}, \quad B_S > B_B$$

where the B's are the brightness of the source and background respectively. Note that for $B_B = 0$, the contrast is unity. This case will be considered first.

From the general photometric equation, expressed in photometric units, and assuming $\cos \alpha_S = \cos \alpha_R = 1$, the luminous flux on the collector is

$$dF = \frac{B dS_S}{R^2} \cdot dS_R \quad \text{lumens, or}$$

$$F = \frac{I_o \rho_S dS_S}{R^2} \cdot dS_R$$

where

I_o = ambient illumination of the obstacle field

ρ_S = the diffuse reflectance of the source

B = source brightness, lamberts

Since in the present case,

$dS_S = \omega R d_W$, where d_W is the (wire) obstacle

diameter, we may write

$$dF = \frac{I_o \rho_S \omega d_W \pi D^2}{4R} \quad \text{lumens.}$$

Note that, except for losses, all radiation collected by the objective is incident upon the image element.

From Table 25,

$R = 1000 \cdot 12 \cdot 2.54 = 30{,}500$ cm

$d_W = .125$ inch $= .318$ cm

$D = 2.8$ cm

Two extreme conditions of illumination will be taken: (a) bright sunlight (sun at zenith) $I = 10{,}000$ foot-candles and (b) full moon, $I_o = .03$ foot-candle. Assume that ρ_S', the reflectivity of the wire obstacle, $= .5$.

Note that for

(a) $I_o \rho_S = 10^4 \cdot 1.08 \cdot 10^{-3} \cdot .5$

$= 5.4$ lumens cm^{-2} (lamberts)

(b) $I_o \rho_S = 3.10^{-2} \cdot 1.08 \cdot 10^{-3} \cdot .5$

$$= 1.6 \cdot 10^{-5} \text{ lamberts}$$

Furthermore, assume the daylight spectral distribution of radiation, 6000°K, and the mechanical equivalent of radiation to be

$$L_e = 200 \text{ lumens watt}^{-1};$$

the irradiant flux from the wire upon the image element then becomes for bright sunlight

$$dP = 3.7 \,.\, 10^{-10} \text{ watts.}$$

Since the NEP per image element at frame rates of approximately 30 sec^{-1} is of the order of to 10^{-13} watt, there is ample signal for detection of the wire, in bright sunlight, assuming unity contrast as indicated above.

For the case of illumination by full moon,

$dP = 1.1 \cdot 10^{-15}$ watts, which is too small a value to be practical.

For the purpose of more complete description of the physical situation, two contrasts are defined:

(a) Obstacle-to-background contrast in the element C_e, and

(b) Element-to-element contrast, C_{ee}

where one element contains the image of the obstacle within its boundary, and the adjacent scanned element contains background only.

In terms of photons,

$$C_e = \frac{n_{(S+B)} - n_B}{n_{(S+B)}}$$

where

$n_{(S+B)}$ = radiant flux in photons sec^{-1} on the image element due to both obstacle and background

n_B = radiant flux in photons sec^{-1} on the same image element due to background alone.

Expressed in terms of radiance,

$$C_{ee} = \frac{B_{(S+B)}\, dS_\omega - B_B\, (dS_\omega - dS_S)}{B_{(S+B)}\, dS_\omega} .$$

In case (b), the element-to-element contrast, C_{ee}, in terms of photon flux is given by

$$C_{ee} = \frac{n_{(S+B)} - n_B}{n_{(S+B)}}$$

where

$n_{(S+B)}$ = radiant flux in photons sec^{-1} on the image element due to source and its background

n_B = radiant flux on an adjacent element due to background expressed in terms of radiance

$$C_{ee} = \frac{B_S \, dS_S + B_B \, (dS_\omega - dS_S) - B_B \, dS_\omega}{}$$

or

$$C_{ee} = \frac{(B_S - B_B) \, dS_S}{(B_S - B_B) \, dS_S + B_B dS_\omega} \; .$$

It is of interest to express the value of the luminous flux increment, dF, as the element containing the obstacle of brightness, B_S is sampled, assuming that this element is immersed in a matrix of elements illuminated by a uniform background of brightness, B_B:

$$dF = \left[B_S \, dS_S + B_B \, (dS_\omega - dS_S) - B_B \, dS_\omega \right] \frac{dS_R}{R^2} \; .$$

Let ρ_B = the average diffuse reflectance of the background

ρ_S = the average diffuse reflectance of the source.

Then we may write, for the luminous flux on the collector,

$$dF = \left[\rho_S \, dS_S + \rho_B \, (dS_\omega - dS_S) - \rho_B dS_\omega \right] \frac{I_o \, dS_R}{R^2} \; ;$$

and introducing the mechanical equivalent of light, L_e, we obtain the irradiant flux,

$$dP = I_o \, (\rho_S - \rho_B) \frac{dS_S \, dS_R}{L_e R^2} \; ,$$

As an example, again assume that

$I_o = 1000$ foot-candles

$\rho_S = .5$

$\rho_B = .4$

Then for the sensor of Table 25,

$dF \cong 4.5 \cdot 10^{-11}$ watts.

Under the assumption of linearity of response of the photosensor, the S/N would be adequate for a vidicon with an NEP of 10^{-12} watts at a frame rate of 30 per second.

For the case of the full moon,

$P_e \cong 1.3 \cdot 10^{-18}$ watts,

which is inadequate even with image intensification.

APPENDIX III

PROCEDURAL TASK ANALYSIS

The following procedural task analysis was conducted for various flight mission segments using the OH-23 rotary-wing and O-1 fixed-wing aircraft. The purpose of the analysis was to determine whether a typical procedural-control-display relationship existed which could cause inadvertant wire and/or tree strikes. The task analysis included the normal takeoff, climb, descent, hover (rotary-wing), and landing phases of flight. Variations of these procedures, such as crosswind takeoffs and landings, were also included. The analysis disclosed no procedures associated with low-altitude flight which would put undue strain on the pilot and thus cause distraction or confusion.

The procedural analysis is outlined on the following Tables 27 through 33.

TABLE 27
FIXED-WING TAKEOFF PROCEDURE (NORMAL)
(C-1)

TASKS (GROSS TASK) (SUBTASKS)	VEHICLE EQUIPMENT	DISPLAYS	ACTION	FEEDBACK	REMARKS
1. TAKEOFF					
a. Advance throttle (slowly)	Throttle	Tachometer Manifold pressure gauge	Pushes throttle forward	Engine sound increases	Before takeoff is begun, point must be determined which allows sufficient distance for stopping
b. Release brakes	Brake pedals		Relaxes toe pressure and places heels on floor	Aircraft rolls freely	
c. Position control stick for proper takeoff attitude	Control stick		Moves stick	Aircraft assumes proper attitude	Elevator, rudder, and aileron are used continuously. Continuous observation outside aircraft is required
2. AFTER TAKEOFF					
a. Retard throttle	Throttle	Tachometer Manifold pressure gauge	Pulls throttle back	Engine sound reduces	
b. Reduce engine rpm	Propeller control lever	Tachometer	Pulls lever back	Engine sound reduces	
c. Raise wing flaps (if used)	Wing flap switch	Wing flap position indicator	Pushes switch up	Speed, climb rate, and trim changes	
d. Adjust elevator trim	Trim tab control wheel		Rolls wheel aft		
e. Shutoff auxiliary fuel pump	Auxiliary fuel pump switch	Switch panel	Moves switch down		
3. CLIMB					
a. Position control stick to maintain proper climb speed	Control stick	Airspeed indicator	Moves stick		

TABLE 28
FIXED-WING TAKEOFF PROCEDURE (ALTERNATE)
(0-1)

TASKS (GROSS TASK) (SUBTASKS)	VEHICLE EQUIPMENT	DISPLAYS	ACTION	FEEDBACK	REMARKS
1. TAKEOFF (MINIMUM RUN/OBSTACLE CLEARANCE)					
a. Lower wing flaps	Wing flap switch	Flap position indicator	Pushes switch down, then up to neutral	Flap position indicator shows 30°	All flight controls are used continuously during flight
b. Hold brakes	Brake pedals		Presses pedals with feet		
c. Advance throttle (slowly)	Throttle	Tachometer Manifold pressure gauge	Moves throttle forward	Engine sound increases rpm and Manifold Pressure rise	
d. Release brakes	Brake pedal		Releases foot pressure	Aircraft begins to roll	
e. Maintain tail-low takeoff attitude	Control stick	Airspeed indicator	Moves stick	Short roll and lift-off	Proper attitude is maintained to lift-off
2. TAKEOFF (CROSSWING)					
a. Check that wing flaps are up	Wing flap switch	Flap indicator			Minimum flap usage depending on field length
b. Advance throttle (slowly)	Throttle	Tachometer Manifold pressure gauge	Pushes throttle forward	Engine noise increases rpm and Manifold Pressure rise	
c. Maintain tail-high takeoff attitude	Contr l stick	Airspeed indicator	Moves stick		With airspeed well above takeoff speed aircraft is pulled off ground abruptly

TABLE 29
FIXED-WING LANDING PROCEDURE (NORMAL)
(O-1)

TASKS (GROSS TASK) (SUBTASK)	VEHICLE EQUIPMENT	DISPLAYS	ACTION	FEEDBACK	REMARKS
1. DESCENT a. Apply full rich mixture	Mixture control lever		Pushes lever forward		Pilot is continually monitoring engine and flight instruments while maintaining an awareness of events outside the aircraft. Also, flight controls are continuously operated by the pilot to maintain proper flight attitude and direction. The environment determines the extent of radio calls
b. Increase engine rpm	Propeller control lever	Tachometer	Pushes lever forward	Rpm increases to 2300	
c. Apply carburetor heat/alternate air	Carburetor air control lever	Tachometer	Pulls lever back	Slight decrease in rpm	
d. Close throttle	Throttle	Tachometer	Pulls throttle back	Rpm decreases and sound of engine lowers	
e. Establish glide and maintain directional control	Stick Rudder pedals	Airspeed indicator altimeter, compass	Repositions stick and rudder pedals	Airspeed at 80 mph, constant descent	
f. Clear engine	Throttle	Tachometer	Moves throttle lever forward then back	Rpm increases then decreases. Engine sound change	
2. BEFORE LANDING a. Select fullest fuel tank	Fuel tank selector		Rotates selector		
b. Check mixture (rich) and carburetor heat/alternate air	Mixture control lever carburetor air control lever				
c. Switch on auxiliary fuel pump	Auxiliary fuel pump switch		Pushes switch up		
d. Check primer for locked position	Engine primer				
e. Lock shoulder harness	Shoulder harness lock lever		Pulls lever back		
f. Lower wing flaps (as desired)	Wing flap switch	Wing flap position indicator	Pushes switch down to desired setting then up to neutral	Stick forces change Descent increases	
g. Position carburetor air control to ram filtered air (on final approach)	Carburetor air control lever	Tachometer	Pushes lever forward	Slight increase in rpm	

TABLE 29 (Continued)
FIXED WING LANDING PROCEDURE (NORMAL)
(O-1)

TASKS (GROSS TASK) (SUBTASKS)	VEHICLE EQUIPMENT	DISPLAYS	ACTION	FEEDBACK	REMARKS
3. LANDING					
a. Close throttle (180 approach)	Throttle	Tachometer	Pulls throttle back	Rpm decreases and engine sound lowers	
b. Establish normal glide	Stick	Airspeed indicator	Repositions stick	Airspeed is 80 mph and descent is constant	
c. Increase engine rpm (maximum rpm)	Propeller control lever	Tachometer	Pushes lever forward	Rpm increases	Accomplished on final approach
d. Lower wing flaps (as desired)	Wing flap switch	Wing flap position indicator	Pushes switch down to desired setting then to neutral	Stick forces change Descent increases	
e. Establish flap downglide speed	Stick	Airspeed indicator	Reposition stick	Airspeed reduces to 70 mph	
f. Make 3-point or wheel landing	Stick	Looking outside aircraft	Pulls stick back	Sound level lowers and ground contact is made	Stick is primary control, but other controls also play critical roles

TABLE 39
ROTARY-WING TAKEOFF PROCEDURE (NORMAL)
(OH-23)

TASKS (GROSS TASK) (SUBTASK)	VEHICLE EQUIPMENT	DISPLAYS	ACTION	FEEDBACK	REMARKS
1. TAKEOFF					
a. Switch on auxiliary fuel pump	Auxiliary fuel pump switch	Switch panel	Moves switch up		Pilot carefully observes flight-path to determine and avoid all hazardous obstacles during takeoff
b. Advance throttle	Throttle	Dual Tachometer	Turns throttle	Engine sound increases	
c. Apply carburetor heat (as required)	Carburetor heat control lever	Carburetor air temperature indicator	Pulls lever aft		
d. Position cyclic control stick to neutral or slightly into wind	Cyclic control stick		Moves stick		
e. Gradually apply collective pitch	Collective control stick		Pulls up on stick	Helicopter becomes airborne to a hover	Coordination of hands and feet are necessary to maintain proper control. Engine rpm changes may be required
f. Apply cyclic trim forces as desired	Cyclic trim switch	Switch on stick grip	Moves switch in desired direction	Cyclic control pressure changes	
g. Apply cyclic control stick in direction of intended takeoff	Cyclic control stick		Moves stick in desired direction	Helicopter moves horizontally	
2. CLIMB					
a. Accelerate to climb speed	Cyclic control stick collective control stick	Airspeed indicator altmeter	Moves control sticks	Airspeed increases	
b. Maintain airspeed and power settings	Cyclic control stick, collective control stick	Airspeed, tachometer, manifold pressure gauge	Moves control sticks	Engine power indications, airspeed indications	
c. Apply carburetor heat (as required)	Carburetor heat control lever	Carburetor air temperature indicator	Pulls lever aft		

TABLE 31
ROTARY-WING TAKEOFF PROCEDURE (ALTERNATE)
(OH-23)

TASK (GROSS TASK) (SUBTASKS)	VEHICLE EQUIPMENT	DISPLAYS	ACTION	FEEDBACK	REMARKS
1. TAKEOFF (RUNNING)					
a. Advance throttle to maximum permissible rpm (auxiliary fuel pump on)	Throttle	Tachometer Manifold pressure gauge	Turns throttle	Rpm and Manifold Pressure rise, engine noise increases	
b. Increase collective pitch	Collective control stick		Pulls stick up	Helicopter becomes light on its landing gear	
c. Apply forward cyclic control	Cyclic control stick		Pushes stick forward	Helicopter begins to move forward	Anti-torque pedals are used to maintain heading. As helicopter increases speed, cyclic control stick is positioned for lift-off
2. TAKEOFF (JUMP)					
a. Head helicopter into wind					Used where normal or running takeoff is not feasible. Pilot must carefully evaluate such factors as gross weight, density, altitude, surface wind velocity, temperature space available, and experience level before attempting jump takeoff
b. Advance throttle to maximum permissible rpm (auxiliary fuel pump on)	Throttle	Tachometer Manifold pressure gauge	Turns throttle	Rpm and Manifold Pressure rise, engine noise increases	
c. Apply collective pitch rapidly and smoothly	Collective control stick		Moves stick up	Helicopter jumps off ground	
d. Apply forward cyclic control at 2 foot altitude (full throttle)	Cyclic control stick	Tachometer	Moves cyclic stick forward. Moves collectice for rpm control	Helicopter moves forward. Hold minimum altitude until airspeed reaches 30-35 knots	Maintain engine rpm in limits with collective control stick
3. TAKEOFF (CROSSWIND)					
a. Advance throttle to maximum permissible (auxiliary fuel pump on)	Throttle	Tachometer Manifold pressure gauge	Turns throttle	Rpm and Manifold Pressure rise, engine noise increases	
b. Displace cyclic control upwind and apply collective pitch	Cyclic control stick Collective control stick		Move sticks to desired position	Helicopter becomes airborne	
c. Upon lift-off apply forward cyclic control			Moves stick forward	Helicopter moves forward	Turn into wind after clearing obstacles

TABLE 32
ROTARY-WING LANDING PROCEDURES (NORMAL)
(OH-23)

TASKS (GROSS TASK) (SUBTASKS)	VEHICLE EQUIPMENT	DISPLAYS	ACTION	FEEDBACK	REMARKS
1. DESCENT					
a. Switch on auxiliary fuel pump	Auxiliary fuel pump switch	Switch position	Moves switch up		
b. Reduce collective pitch	Collective control stick	Tachometer	Moves handle of down control throttle down	Descent begins, noise level changes	
c. Reposition cyclic control stick	Cyclic control stick	Airspeed indicator, altimeter	Moves stick forward	Maintains 40-50 knots	
d. Adjust carburetor heater lever	Carburetor heat lever	Carburetor air temperature indicator	Moves lever forward or aft	Proper carburetor air temperature indication	
e. Apply collective pitch	Collective control stick	Tachometer	Moves handle of control throttle up	Descent rate reduces noise changes	
2. PRETRAFFIC PROCEDURE					
a. Adjust carburetor heat	Carburetor heat lever	Carburetor air temperature indicator	Moves lever forward or aft	Proper carburetor air temperature indication	
b. Check engine rpm and auxiliary fuel pump switch	Engine rpm indicator auxiliary fuel pump switch	Tachometer switch position	Scans instruments	Engine rpm at 3200	
c. Set altimeter	Altimeter	Altimeter reading	Turns altimeter knob		
d. Shut off cabin heater	Cabin heat control lever		Pushes lever off		
3. LANDING (NORMAL)					
a. Adjust carburetor heat	Carburetor heat lever	Carburetor air temperature indicator	Moves lever forward or off		
b. Check engine rpm and auxiliary fuel pump switch	Engine rpm indicator auxiliary fuel pump switch	Tachometer switch position	Scans instruments	Engine rpm at 3200	
c. Apply collective and cyclic controls	Collective control stick cyclic control stick	Airspeed indicator	Moves collective stick up or down. Moves cyclic stick forward or aft	Airspeed 15 knots Altitude 15 feet Zero ground speed and hover altitude	Much of pilot's attention must be outside aircraft
d. Apply collective and cyclic controls	Collective control stick cyclic control stick	Airspeed indicator	Moves collective stick up or down. Moves cyclic stick forward or aft		Much of pilot's attention must be outside aircraft
e. Reduce collective pitch	Collective control stick		Moves stick down	Slow descent	Upon ground contact reduce collective pitch to minimum (stick full down)

TABLE 33
ROTARY-WING LANDING PROCEDURES (ALTERNATE)
(OH-23)

TASKS (GROSS TASK) (SUBTASKS)	VEHICLE EQUIPMENT	DISPLAYS	ACTION	FEEDBACK	REMARKS
1. DESCENT, RAPID (AUTOROTATIVE)					
a. Adjust carburetor heat lever (as required)	Carburetor heat control lever	Carburetor air temperature indicator	Moves lever		Flight controls are used continuously
b. Switch on auxiliary fuel pump	Auxiliary fuel pump switch	Switch panel	Moves switch up		
c. Place collective pitch control in full down position and decrease throttle to provide approximately 200 rpm separation of tachometers pointers (split needles)	Collective control stick throttle	Tachometer	Moves stick down turns throttle	Helicopter descends rapidly, engine noise decreases, tachometer shows split needles, (200 rpm separation), airspeed indicator shows 40-50 knots IAS	Avoid abrupt movements
d. Maintain 40-50 knots IAS	Cyclic control stick	Airspeed indicator	Moves cyclic stick		
e. Vary collective to maintain rotor speed within specified limits	Collective control stick	Tachometer	Moves collective stick	Proper rpm is maintained	
Recovery - increase engine rpm to 3200 and then apply collective control	Throttle Collective control stick	Tachometer	Turns throttle, pulls collective stick up	Helicopter recovers from descent and lands	Proper height above ground is critical
2. LANDING (CROSSWIND/DOWNWIND) Accomplished in same general manner as normal landing, except that cyclic and anti-torque control must be applied to counter drift or weather-cocking tendancies caused by wind. Additional power and collective pitch may also be required.					

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